The effect of temperature on 3D rock structure of andesite rock sample from potential geothermal area, Sulawesi-Indonesia

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Abstract. An andesite rock sample was taken from potential geothermal area on Lili-Sepporaki, west Sulawesi. The sample is an impermeable cap rock with a high silica mineral at alteration zone around a manifestation. Its Three-dimensional rock structure was analyzed to see its deformation due to temperature change. Change of temperature from 24˚C to 100˚C, 150˚C, 200˚C, and 250˚C was applied to the sample. Subsequent to each change of temperature, the sample was scanned using a micro-Computed Tomography Scan (µ-CT Scan). From the scanning process, a sub-volume 300³ pixels were reconstructed, and its 3D pore and mineral structure were characterized. It is found that porosity \( \phi (T) \), specific surface area \( SsA (T) \) decrease polynomial for pore structure and increase polynomial as temperature increases. This result show that as temperature increases the volume of mineral is bigger make the pore volume smaller. The Fractal dimension for pore structure (2.65 ± 0.02) and for mineral structure (2.89 ± 0.015).

1. Introduction

It is estimated about 40% reserves geothermal energy of the worlds is in Indonesia which makes the country has the largest geothermal energy reserves, therefore has high potential renewable energy sources. However, most of the potential has not been exploited. Indonesia only used 4-5% of its geothermal capacity. However, most of the sources were identified to be undersea, thus specific research involving the rock structure is on the odd occasion. On the other hands, research regarding various type of rocks in geothermal systems has been conducted, mainly to understand the nature of the pore structure of the source rocks such as igneous rocks.

With regards to the pore structure, parameters such as porosity, pore volume, specific surface area, and interconnected pores are often analyzed to characterize rock samples [1]. Among many research regarding igneous rocks, the effect of temperatures changes on an igneous rock has been conducted by Nurmalasari and Fauzi [2] where it was found that porosity decreases as temperature increases. In this research, the effect of temperature changes to igneous rock (an andesite rock) structure. Andesite rocks are often characterized to have low porosity and low permeability [3], thus the analysis is performed on the pore spaces as well as the mineral structure.
2. Methods

Potential geothermal area Lili-Sepporaki, West Sulawesi (see Figure 1) has a manifestation of springs with temperatures 97°C. Study from the rock sample shows that the samples have a high silica mineral at alteration zone around a manifestation, which makes the sample impermeable. An andesite rock sample was cored into cylindrical with 4.5 cm diameter and 4 cm height as shown in Figure 2.

![Figure 1. Location of sample was taken.](image1)

![Figure 2. Sample after formed.](image2)

The andesite rocks were then a change temperature of 24°C, 100°C, 150°C, 200°C, and 250°C using an oven (see Figure 3). According to Zhang et al [4] and Uvarova et al [5], the sample is heated until it reaches the target temperature and the temperature is heat constant for 30 minutes before the sample is removed from the oven, and returned the room temperature. This is important to avoid subsequently the sample was scanned using Bruker Sky Scan 1173 Micro CT Scanning system (see Figure 4 and 5).

![Figure 3. Oven OF-02 for Heated Treatment.](image3)

![Figure 4. µ-CT Scan 1173.](image4)

![Figure 5. Sample on µ-CT Scan.](image5)
The scanning process produced a set of grayscale raw-projection images in the form of 16-bit TIFF images. These images were fine reconstructed to obtain the 3D map of the rock structure in the form of 8-bit BMP images. The reconstructed images (grayscale) describe the relative density of the rock components where darker objects are related to low density materials (or pore) and the brighter objects are related to denser materials (or solid). The reconstructed images were then processed and characterized using steps as shown in Figure 6.

Figure 6. Steps on Digital Image Analysed Processing.

Region of interest sized is $300 \times 300 \times 300$ pixels because in this works the total pixels more than that and the grayscale images aren’t has a same quality. ROI has a upper on the sample and more than left. Using global threshold method because all of grayscale images will be changes to binary images, and global threshold method it’s the simple method. DE speckle for decreases ambiguity on the result of threshold method, and remove less than 4 pixels has given mineral structure and remove more than 4 pixels has given pores structure.

Porosity $\phi$ equation (1) is defined as,

$$\phi = \frac{v_p}{v} = 1 - \frac{v_m}{v}, \quad (1)$$

Where $v_p$ is volume of total pore and $v_o$ is volume of solid and $V$ is total volume of the sub-volume. Total porosity includes are pores on the rocks and the volume of pore only the open of porosity have an interconnected pore [1]. The specific surface area is defined as

$$SSA = \frac{A_{por}}{V_{mat}}. \quad (2)$$

In this work fractal characterized calculated used 3D box counting. Fractal dimension algorithm [6], [7] used for both 3D pore structure and mineral structure.

3. Results and Discussion

3.1. Pore Structure

The characterization for the sample includes the calculating of $\phi$, SSA, and DF [8,9]. Binary image the sub volume size of $300 \times 300 \times 300$ pixels was reconstructed the images from each temperature changes is visualized in 3D space using CT-Vox (see Figure 7) where white objects are the pore spaces. It can be qualitatively observed that the pore volume decreases as temperature increases. In Figure 7 it is shown by the decreasing number of white objects. Quantitatively, Figure 8 shows the plot of Temperature vs porosity. The pattern is similar as that of the SSA (see Figure 9).
Figure 7. Pore structure at Temperature (a) 24°C (b) 100°C (c) 150°C (d) 200°C and (e) 250°C.

Figure 8. Porosity vs Temperature.
The porosity and specific surface area describe pore structure changing as temperature change. The porosity decrease as temperature increases because the pores are closed by minerals. When the temperatures changes make an expand of minerals. Then makes the specific surface area of pores decrease too as temperature increases.

For 3D fractal dimension can give the information of how pores disperse or congregate by temperature change. At temperatures 24˚C Npore it’s 204308. When the temperature raise into 100˚C the pore is congregate and it cause the Npore is 198721, less than before. At the temperatures 150˚C the pore is disperse cause the Npore its 201201 and that is more than from 150˚C. When the temperature raise into 200˚C has been Npore 190196 and the pore is congregate. And when the temperatures 250˚C the pore is congregate cause the Npore is 146274. Fractal dimension function as temperature increases as shown in Figure 10.

3.2. Mineral Structure
The mineral structure images from each temperature changes are visualized in 3D space using CT-Vox (see Fig 11) where white objects are the mineral spaces. It can be qualitatively observed that the mineral volume increases as temperature increases. In Figure 11 it is shown by the increasing number of white
objects. Quantitatively, Figure 12 shows the plot of Temperature vs density. The pattern is similar as that of the SsA (see Figure 13).

Figure 11. Mineral structure at Temperature (a) 24°C (b) 100°C (c) 150°C (d) 200°C and (e) 250°C.

Figure 12. Density vs Temperature.
Figure 13. Surface Specific Area vs Temperature.

The density and specific surface area describe mineral structure changing as temperature change. The density of minerals increase as temperature increases because the silica on the rocks as a mineral was expand. Then makes the specific surface area of mineral increase as temperature increases because the expand of silica.

For 3D fractal dimension can give the information of how mineral disperse or congregate by temperature. At temperatures 24°C Npore 1358961. When the temperature raise into 100°C the pore is disperse and it is cause the Npore is 1344583, that less than from the first heat treatment. At the temperatures 150°C the pore is disperse because the Npore is 1416100 it’s more than from Npore on the temperatures 100°C. Temperature raise into 200°C has been Npore 1444472 and the pore is disperse. And when the temperatures 250°C the pore is disperse cause the Npore 1621111. Fractal dimension of mineral increases as temperatures increases as shown in Figure 16.

Figure 14. Fractal Dimension vs Temperature.

4. Conclusions
From the analysis it is found that the pore structure is highly affected by temperature change. The similar pattern is also appeared for mineral-filled pores. Analysis of the fractal characterized show the pores and mineral-filled pores was disperse or congregate by N sub cube of pores and mineral-filled pores.
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