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Application of volumetric methods in estimating geothermal potential based on reservoir physical parameters
(a case study of geothermal area "Z")

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ABSTRACT

Geothermal is a renewable energy strategically developed in Indonesia, but its utilization has not been maximized. Geothermal exploration requires high costs, so estimating energy reserves in potential areas is essential. This study was conducted to determine the electrical energy potential of geothermal area "Z" by volumetric method and determine the influence of saturation, porosity, and length of generation time on the potential of geothermal electrical energy. The volumetric method used is the *lumped parameter model*. The calculation was carried out with variations in water saturation 0% - 80%, rock porosity 10% - 40%, and the length of generation time 25 - 40 years. The highest estimated electrical energy of geothermal area "Z" is 188 MWe obtained at 80% water saturation, 10% porosity, and 25 years generation duration, while the lowest is 80 MWe obtained with 0% water saturation, 40% porosity, and 40 years of generation duration. At the same porosity, the greater the water saturation, the greater the value of geothermal electricity reserves of the area "Z." The greater the porosity, the greater the effect of increasing water saturation on increasing electrical energy reserves. The large porosity of rocks causes their energy to be smaller since the heat dominance of geothermal regions "Z" is given by the heat of rocks. The length of generation time affects the amount of geothermal electrical energy, that is, the longer the production time, the smaller the reserve.

Keywords: electricity, geothermal, volumetric

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INTRODUCTION

Facing the issue of energy scarcity in the future and global warming, various innovations based on renewable alternative energy have been widely developed, including geothermal energy. But in fact, of Indonesia's total geothermal potential of 23,765.5 MWe, only about 9% has been utilized for power plants (ESDM, 2023). Even though this geothermal resource is a sustainable, environmentally friendly energy with several advantages, including it cannot be exported, can only be used for domestic consumption, free from the risk of increasing (fluctuations) of fossil fuels, does not depend on weather, *suppliers*, and the availability of transportation and loading and unloading facilities in fuel supply, and does not require large land. (Wardani, 2017). With these various advantages and supported by Indonesia's geographical location in the Ring of *Fire* (a row of active and potentially active volcanoes), geothermal energy will be very prospective and strategic to be developed.

To develop geothermal energy, geothermal resources must be explored to utilize the heat generated as electrical energy. Geothermal exploration requires significant capital, high risk, and adequate personal expertise, so calculations are essential to estimate the amount of energy reserves stored in a potential area. This estimation can be done by assessing geothermal potential areas through geological, geochemical, and geophysical research. In some studies, reservoir physical meters such as porosity, water saturation, permeability (Iqbal et al., 2020; Ashat et al., 2019), reservoir area, temperature, and thickness (Utami, 2015) are essential to consider in estimation. Therefore, this study was conducted to determine the potential of electrical energy in geothermal area "Z" by volumetric method and determine the influence of saturation, porosity, and length of generation time on geothermal electrical energy potential.

RESEARCH METHODS

This research was conducted using a volumetric method that estimates the amount of electrical energy potential in an area based on integrating geological investigation data, geochemistry, geophysics, reservoir characteristics, and electrical equivalence estimates. The volumetric method used in this study is a *lumped parameter* model namely, the calculation of geothermal potential estimation is carried out by calculating the content of thermal energy in rocks and heat in the fluid (steam and water, if the geothermal system is two phases) in the reservoir assuming uniform parameters (Hafsari et al., 2017). In simple terms, the heat in a reservoir can be obtained by summing the heat in fluids and rocks. The basic principle of this volumetric method is that the reservoir of geothermal heat is assumed to be a box-shaped system. The reservoir volume is obtained from the multiplication between the distribution area and the thickness of the reservoir (Rasheed et al., 2016; Habibirahman et al., 2019).

The data needed to perform calculations with this volumetric method, namely: a) geothermal potential area data, b) thickness, c) reservoir temperature, d) porosity saturation of geothermal systems (steam and water), e) rock density, f) thermal conductivity of rocks, g) geothermal system density (steam and water), h) energy in geothermal systems (steam and water).

The calculation is done using the MATLAB application. In this calculation, an area's area is based on the contour lines that exist on the surface of the geothermal area. The contour line interprets geophysical data carried out in the geothermal prospect area. Measurement can be done in two ways, namely by making grids over the area of the potential reservoir area and by calculating the area by multiplying the area formula of rectangles and triangles.

The potential of electrical energy in geothermal areas can be obtained through the conversion of thermal energy that can be utilized into electrical energy. The conversion is carried out with several assumptions, namely geothermal area "Z" is a suspected reserve, uniform parameter model *(lumped parameter)*, fluid is static, no energy transfer, electricity generation duration is 25 to 40 years, the gain factor is 25%, and the electricity conversion factor is 10%. In this case, variations in rock porosity were carried out, namely 10%, 15%, 20%, 25%, 30%, 35%, and 40%, and changes in water saturation ranging from 0% to 80% with an increase of 10%. The length of electricity generation varies from 25 years to 40 years with an interval of 5 years. These variations were carried out to determine the influence of porosity, saturation, and generation duration on the magnitude of geothermal heat. Based on these assumptions, the calculation of geothermal energy potential by volumetric method can be done by the following procedure (BSN, 1999; BSN, 2000):

Calculate the heat energy content in the initial state *(Ti)* using equation (1).

$$H_e i = A.h\left[\left(1-\phi\right)\rho_r.c_r.T_i + \phi\left(S_l.\rho_l u_l + S_v.\rho_v u_v\right)_i\right] \tag{1}$$

Calculate the heat energy content in the final state (*Tf*) using equation (2)

$$H_e f = A.h\left[\left(1-\phi\right)\rho_r.c_r.T_f + \phi\left(S_l.\rho_l u_l + S_v.\rho_v u_v\right)_f\right] \tag{2}$$

To calculate the maximum heat energy that can be utilized using the following equation (3):

$$H_{th} = H_e i - H_e f \tag{3}$$

Calculating geothermal energy that can be utilized in reality (in kJ) is by using the following equation (4):

$$H_{de} = R_F.H_{th} \tag{4}$$

Calculate the amount of thermal energy reserves that can be utilized for one year (in MW thermal units) using equation (5):

$$H_{\text{thermal}} = \frac{H_{de}}{t \times 356 \times 24 \times 3600 \times 1000} \tag{5}$$

Calculate the energy that can be generated for a period of *t* years (MWe) or the magnitude of the electrical potential using the following equation (6):

$$H_{el} = \eta \times H_{\text{thermal}} \tag{6}$$

Information,

A : Geothermal area (m^2)
h : Tebal reservoir (m)
Sl : Water saturation (fraction)
Sv : Vapor saturation (fraction)
ul : Energy in water (kJ/kg)
uv : Energy in steam (kJ/kg)
√ : Porosity of reservoir rocks (fractions)
cr : Rock heat capacity (kJ/kg^{o}C)
ρr : Densitas batuan (kg/m^3)
RL : Densitas air (kg/m^3)
ρv : UAP densitas (kg/m^3)
In : Temperature at initial state (^{o}C)
Tf : Temperature in the final state, namely with the understanding of geothermal energy in the reservoir, is no longer economical to be used as a power plant (^{o}C)
He : Maximum amount of heat energy that can be utilized (kJ)
Hth : Geothermal energy that can be utilized in reality (kJ)
Hthermal : Geothermal energy that can be utilized within a certain period (MW thermal)
Hel : Electrical energy that can be generated over a certain period (MWe)

RF : Gain factor (%)
t : Length of time of power generation (years)
η : Electric conversion factor

RESULTS AND DISCUSSION

The volumetric method estimates the electrical energy potential of the geothermal area "Z" (Figure 1). One of the essential parameters used is the volume of the reservoir, obtained by multiplying the area of the reservoir by the thickness of the reservoir. Based on the results of geophysical surveys using gravity, geomagnetic, and CSAMT methods, geothermal area data "Z" is presented in Table 1.

Table 1. Physical parameter data of geothermal area "Z"

Besaran	Beginning	End
Speed (km^2)	20	
Thickness(m)	2000	
Rock heat capacity (kJ/kg^{o}C)	1	
Densitas batuan (kg/m^3)	2500	
Temperature reservoir (^{o}C)	240	180

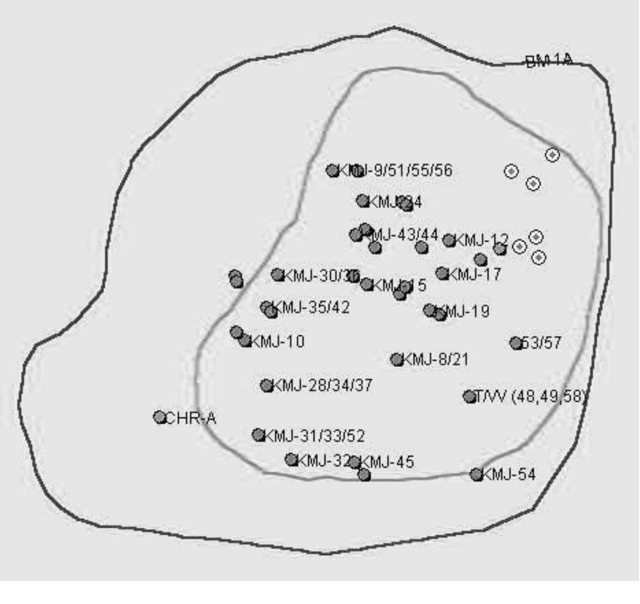

Figure 1. The appearance of the geothermal region "Z"

The initial and final temperature of the reservoir affects the magnitude of pressure, the volume of liquids and vapors, and the energy in liquids and vapors. In this case, the value of such quantities can be known using the steam table. Using the data in the vapor table, the density of liquid and vapor can be determined using the ratio between mass and fluid phase volume. The volume of the fluid phase is indicated by the volume of the liquid and the specific volume of the vapor. At a temperature of 240^{o}C the density of the liquid is 813.669 kg /m^3, and the density of vapor is 16.733 kg /m^3. While at a temperature of 180^{o}C, liquid and vapor density were obtained respectively 887, 311 kg /m^3 and 5.153 kg /m^3 (Koretsky, 2004).

The MATLAB data processing results are presented in graphic form, as shown in Figure 2. It is known that during 25 years of generation, the most significant amount of electrical energy reserves were obtained at 10% porosity with 80% water saturation, which resulted in an estimated value of 188 MWe, as shown in Figure 2a. In contrast, the calculated results with a porosity of 40%, 0% saturation, and the smallest reserve of 129 MWe. Such is the case in production years of 30 years, 35 years, and 40 years, where the largest reserve value is obtained at 10% porosity with 80% water saturation, while the smallest potential for electrical energy occurs when porosity is 40% and water saturation is 0%. The largest reserve value within 30 years is 157 MWe, within 35 years, it is 134 MWe, and within 40 years is 117 MWe. The smallest reserves in production times of 30 years, 35 years, and 40 years, respectively, are 107 MWe, 92 MWe, and 80 MWe. This result shows that the smaller the porosity value and the greater the saturation, the greater the electrical energy produced.

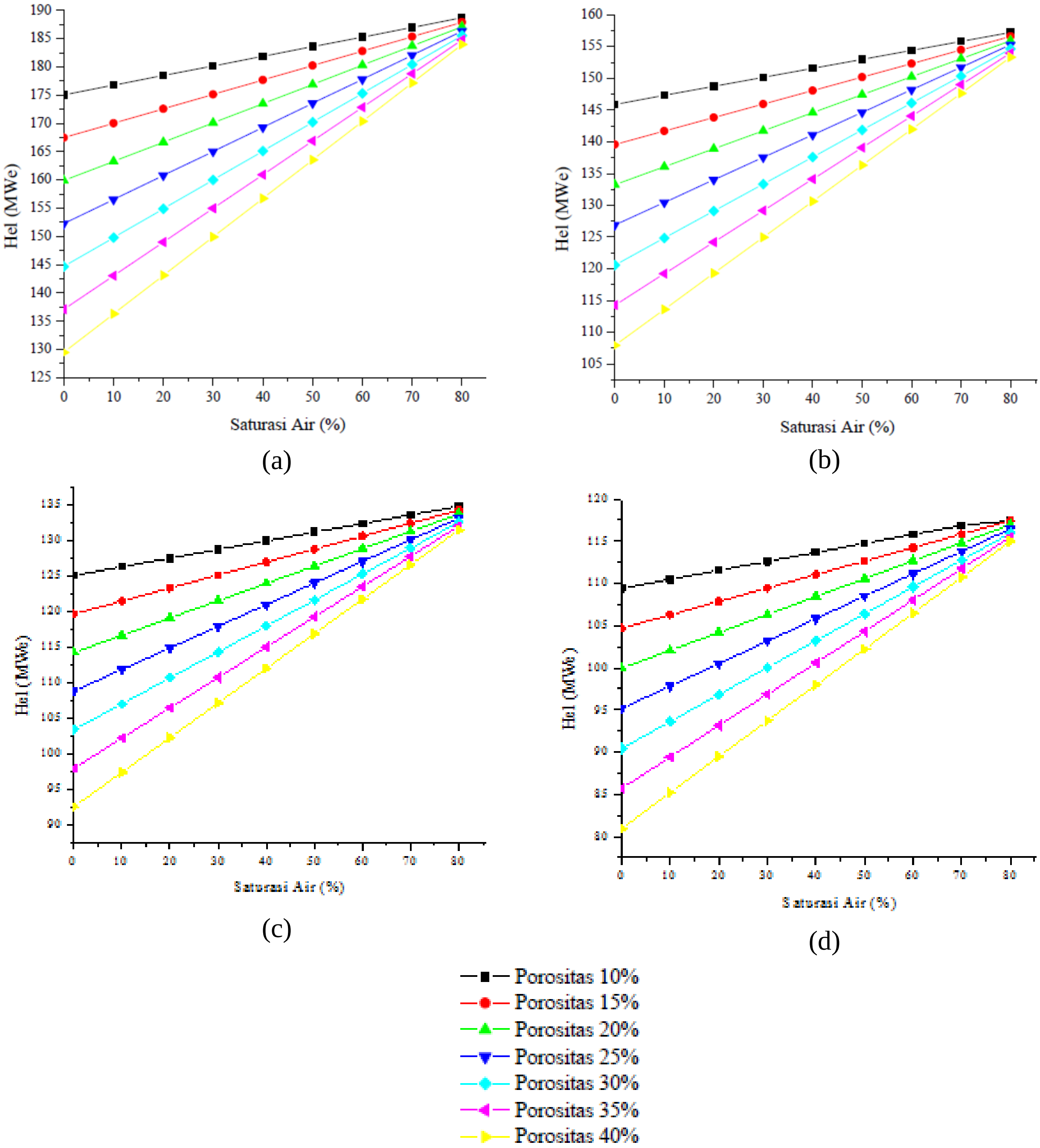

Figure 2. Effect of water saturation and rock porosity on *Hel* for (a) 25 years, (b) 30 years, (c) 35 years, (d) 40 years of generation

As shown in the graph in Figure 2, water saturation, porosity, and generation duration affect geothermal electrical energy potential. According to Iqbal et al. (2020), porosity and water saturation are essential and main parameters in geothermal estimation. By varying the saturation of water, it can be seen that saturation is one of the factors that can increase the magnitude of geothermal electrical energy namely, at the same porosity, the reserve of electrical energy will be greater with an increase in water saturation or the reserve of electrical energy will be greater if the steam saturation is smaller. This happens because the specific heat of water is greater than the specific heat of steam. However, this water saturation parameter must be considered in estimating because the more significant the saturation, the greater the possibility of *overestimation* (Zhang et al., 2009). Figure 2a - d shows that with variations in water saturation and porosity of rocks, the greater the porosity of rocks, the greater the influence of water saturation in increasing geothermal electrical energy, as seen from the greater gradient of the line. This is in line with the results of research conducted by Zhang et al. (2009) and Sun et al. (2010), namely, if the porosity is smaller, then the increase in water saturation and high temperature of the reservoir becomes less significant in increasing the potential of geothermal electrical energy. If the porosity value is high, each increase in water saturation will cause a greater line gradient value.

In contrast, the resulting line gradient is also small for small porosity with a continuously rising saturation level. At the same saturation and porosity changes, the electrical energy produced by the geothermal region "Z" becomes smaller with increasing porosity. This can be explained because the heat of rocks in the geothermal region "Z" dominates compared to fluid heat. Hence, the porosity effect is more significant in reducing the electricity potential of geothermal areas.

Geothermal systems can be productive and must have low porosity, high thermal conductivity and permeability, large enough volume size, high temperature, sufficient fluid content, and silica content in their reservoir rocks (Suharno, 2009 in Donovan, 2020). Based on these criteria, in this estimation, it appears that porosity impacts the decreasing potential of geothermal electricity. Still, porosity has an essential influence because porosity can form good permeability to help extract heat, which is generally transferred through liquid or steam before being used to drive turbines or generators. So, with the greater the porosity value, the heat extraction process will become easier even though the amount of electrical energy produced is getting smaller.

Furthermore, the effect of the length of generation time can be known by looking at Figure 2. The longer the generation time, the smaller the energy reserves produced. This happens because the longer the production time, the more heat is produced, according to Equation 5. In addition, it is seen that the longer the production period and the more significant the saturation, the greater the decrease in energy potential produced, but the influence of porosity is less significant.

CONCLUSION

This study uses volumetric methods, so paying attention to reservoir dimensions, initial and final temperatures, saturation, porosity, heat capacity of rocks, energy in steam and water, rock density, water density, and steam density is important. The result of estimating the largest electrical energy reserves for geothermal area "Z" with this method is 188 MWe obtained if water saturation is 80%, rock porosity is 10%, and generation duration is 25 years. The smallest estimated electrical energy reserves of geothermal area "Z" is 80 MWe obtained if water saturation is 0%, rock porosity is 40%, and generation duration is 40 years. The physical parameters of the reservoir, namely water saturation and porosity of rocks, affect the size of energy reserves. The greater the saturation of water at the same porosity, the greater the value of the electrical energy reserves of the area "Z" is greater. The greater the porosity, the greater the effect of increasing water saturation on increasing electrical energy reserves. The large porosity of rocks causes the energy produced to be smaller, meaning that the dominance of geothermal area heat "Z" is given by rock heat. In addition to the physical parameters of the reservoir, the length of generation time also affects the estimated amount of geothermal electrical energy; the longer the production time/generation time, the smaller the reserve.

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