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Prediction of the distribution of geothermal sources based on the geothermal temperature gradient in the Blawan Bondowoso

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ABSTRACT

This study was carried out on the distribution of temperature gradients and heat transfer in the Blawan geothermal field, using a temperature sensor to detect the below-ground temperatures to a depth of 2 m with five sensors. Each of these sensors is able to record temperature with an interval of 30 s. The temperature distribution of the legible data indicates that the highest temperature value has been recorded. Reservoir temperature estimation models were obtained at a depth of 2000 m by 194 °C. Furthermore, the heat flow rate on slaves 1, 2, 3 and 4 were 192.837, 309.046, 517.916 and 228.533 W/m^2, respectively. Based on the results of the heat flow calculation, it was discovered that the greater the temperature gradient value, the higher the rate of heat flow occurring at the drill point.

1. Introduction

Geothermal is an alternative energy with an enormous potential of been used as a power plant. Indonesia is the totality of the countries with 256 geothermal locations having a potential of 28.1 GWe [1]. However, it is presently placed 3rd in its utilization and use as a power plant [2]. This has promoted the government in 2023 to place Indonesia first in the utilization of geothermal energy.

One of the locations of geothermal prospects in East Java is Blawan-Ijen, which has a potential of 270 MW. Blawan is an area located in the Sempol Sub-district of Bondowoso with the emergence of geothermal manifestations in the form of hot water. The existence of these manifestations is due to a fault that occurs in the northern area of the Ijen caldera which is called the Blawan fault [3]. Geothermal development as appropriate energy is continuously carried out with the aim of discovering geothermal resources such as preliminary surveys (geophysical surveys, geochemistry, temperature, and geological conditions).

Preliminary study using geophysical methods has been carried out among other methods, including geomagnetic [3,4], resistivity [5,6], gravity [7] geothermometer [8], and magnetotelluric [1] which explains that geothermal blawan is characterized by hot springs that occur due to lower seepage of the surface corresponding to the fault direction. However, from this study, none of these have identified the determining temperature distribution and gradient in the Blawan's area.

The study of reservoir temperature is instrumental in determining geothermal potential. This aims to evaluate temperature and heat transfer models below the surface as the geothermal system that may be characterized by the high level of underground temperatures [9,10]. One of the methods for determining temperature distribution and gradient, heat transfer and the estimation of

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reservoir temperature [11] is the drilling of the ramps temperature using a temperature sensor (Fig. 1). Due to these problems, a study needs to be carried out in order to estimate the temperature distribution and gradient, heat transfer and temperature estimation in the reservoir.

2. Regional geology

Geographically, the study area of Blawan resides in Bondowoso District, which has a coordinate point of S07°59′13.2" - S12°62′15.1″ and E113°08′27.6" - E114°10′32.8" [12]. Blawan Village which is a meeting point of the two large rivers Kalisat and Banyupahit (Fig. 2), has a distance of 17 km northwest of the crater Ijen.

In the study area, two different volcanic-rock stratigraphies are located on the young and old Ijen volcano which is composed of Tuff Rocks, Volcano Breccia and lava. The tuffs have a light white-gray colour, smooth, easily kneaded and irregularly layered. Furthermore, the volcanic breccia has a yellowish-gray colour, gravel-sized to chunks, basalt and andesite components that are angled and circularly twisted with the basic mass of tuff while, the lava consist of andesite basalt, scoria, gray and Porfiritic.

The Ijen Old volcano consists of volcano breccia, coal breccia and tuff. This volcanic breccia is yellowish gray in colour, its components are angled, consisting of andesite, basalt and obsidian and bulleted lapilli until the bomb. Conversely, the gray-colored breccia and components of the bribery consist of a floating, lapilli-sized until the bomb. The masses are essentially tuff, which is an eruption of the oldest Ijen volcano and the old Ijen, in which the former may still be seen on LANDSAT imagery. This rock spread is located in the northern part of the mapping area, including M. Malang. M. Kendeng. M. Ringgit. M. Pawean. M. Blau and M. Kukusan. The rocks are usually covered by tropical forests [13].

3. Materials and methods

Heat always flows from a higher to a lower temperature. The rate of hear transfer through comparable objects to the gradient temperature (different temperature per unit length) is.

Suppose a rock that has a length and width with a lower temperature (T_1) and the upper (T_2) with a depth of x, the time of heat flow per unit area through the rock is $((T_2\text{-}T_1)/x)$.

$q = -k\,\frac{dT}{dx}$ the conduction rate of heat transfer occurs in proportion to the temperature gradient magnitude and the opposite direction. With the value of conductivity coefficient k. Therefore [11],:

$$q = -k\,\frac{T_2 - T_1}{x} \tag{1}$$

The tool used in this study was the temperature sensor DS18B20 which consists of 5 vertical sensors that are vertically composed with a depth of 2 m with a distance of 0.4 m in each. Five sensors read the ground temperature every 30 s and temporarily stored it on the slave part (consisting of 4 slaves). The signal temperature readings stored in the slave were sent via wireless NRF24L01 to the master and the data was stored on the master using Micro SD Card (Fig. 3).

Data acquisition has carried out on September 9, 2019 in the manifestation of Blawan's geothermal near the hot spring baths by inserting five sensors in the ground having a depth of 0.4 m, 0.8 m, 1.2 m, 1.6 m and 2 m at 4 different points (forming a square) with a distance of 2 m between points (Fig. 4).

The measurement was carried out for approximately 8 h and the recorded data (time and temperature) were processed using *Microsoft Excel* in order to determine the relationship between the measurement times and temperature, indicating that at that point, it is still affected by the surface temperature. In addition, the heat flow rate was calculated using the calculation method, which ensures

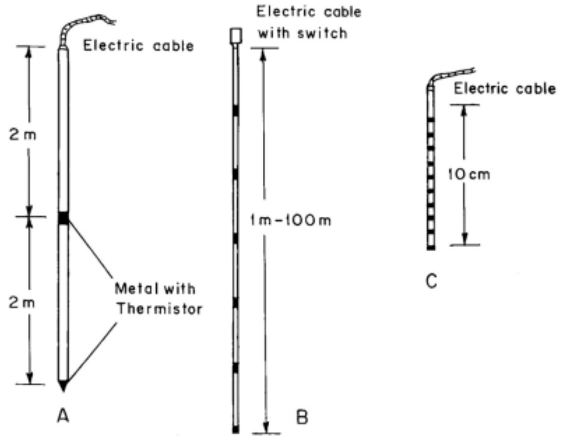

Fig. 1. An example of a temperature sensor used to measure drilling temperatures [11].

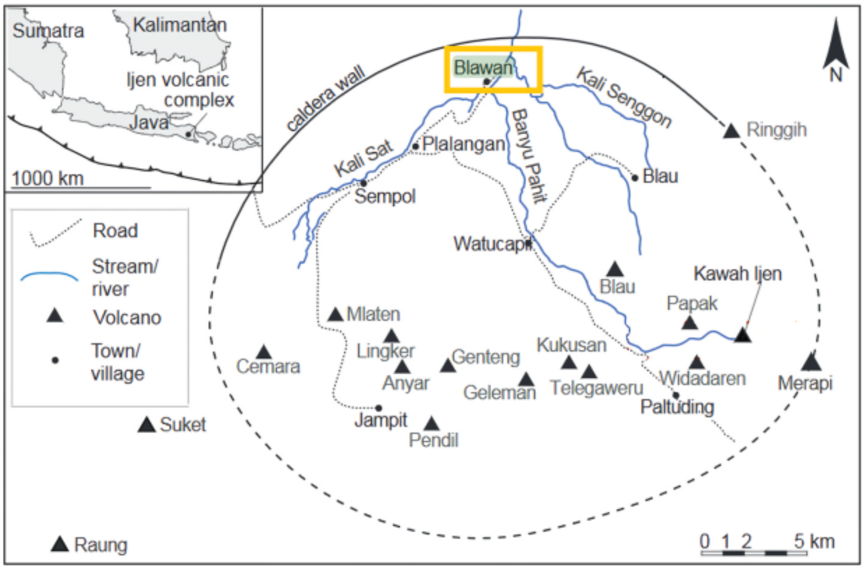

Fig. 2. Research location [14].

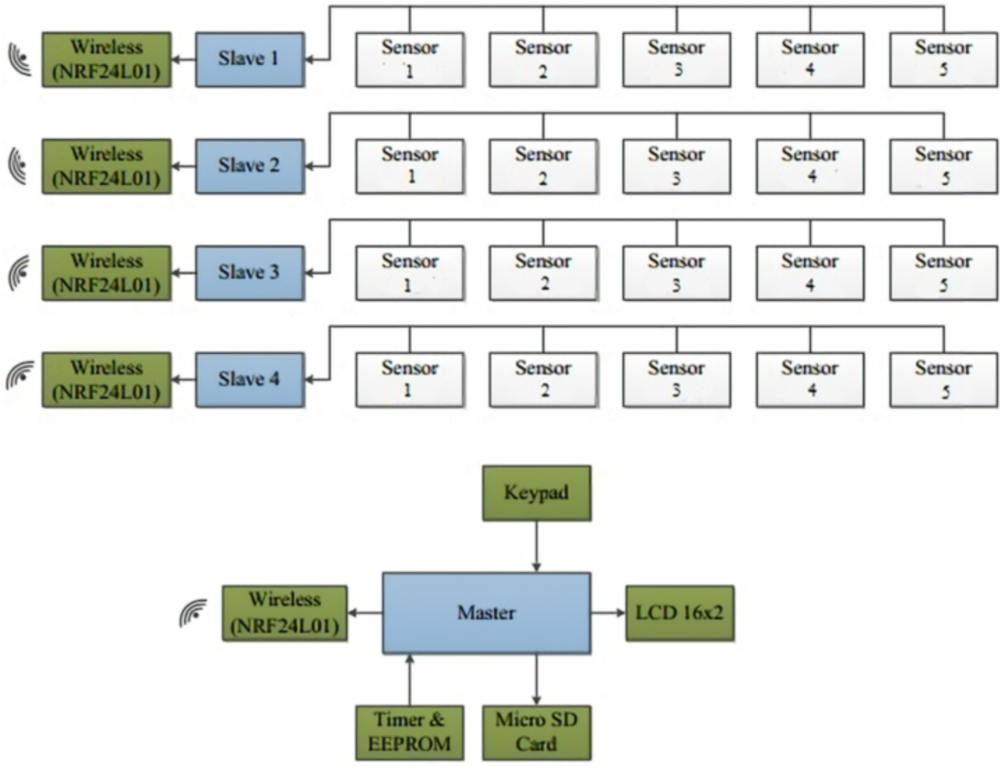

Fig. 3. Temperature measuring Instruments.

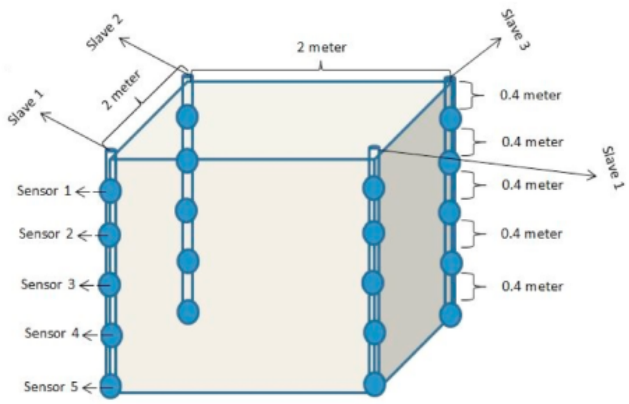

Fig. 4. Method of data acquisition.

that it is analyzed at each drill point.

4. Result and discussion

Based on the results of the stored measurements for 8 h, it was observed that there is a difference in the temperature of each slave. Slave Data 1, 2, 3 and 4 represented in (Fig. 5), (Fig. 6) (Fig. 7) and (Fig. 8), respectively shows an almost constant temperature value. Meanwhile, the depth of 0.4 m from the surface on sensor one on all slaves shows a striking difference in measurement data. This is because the sensor is still affected by the surface temperature of the earth. Furthermore, it was observed that at nine o'clock, the average temperature experienced increased.

Slaves 1, 2, 3 and 4 had the highest temperature at 34.63 °C, 47.94 °C, 49 °C and 47.94 °C, respectively. Slaves two and 4 had high values because they are near hot springs and it is interpreted that subsurface rocks have small porosity compared to rocks with large thermal conductivity values. In the volcanic process, fluid conductivity, porosity and saturation may change significantly, where porosity may be reduced by the formation of alteration minerals chemically.

Geothermal systems are based on the thermal conductivity commonly used around 3.0 W/m.K [15]. A series of discrete temperature values in the formation of cored for thermal conductivity are used to obtain heat flow values [16]. Generally, the distribution of geothermal resources near the temperature surface is increasing to the northwest. The results of the average measurement for each slave are shown in Table 1.

Based on the average result in Table 1, it may be a group according to the location of the drilling point and drill depth. Therefore, it is subject to Table 2, where the results of temperature gradients in each successive slave were 1.92 °C/m 3.08 °C/m 5.15 °C/m and 2.27 °C/m. Temperature gradients were changing laterally, even at the same depth. The influence of temperature changes by the geothermal manifestations has also influenced the thermal conductivity of rocks, climate change, rock thickness, depth and porosity of each layer.

The estimation of geothermal temperature in the area was carried out using the polynomial method at a depth of 2000 m at 194 °C (Fig. 9), including a moderate reservoir temperature (125 °C–225 °C) [17,18], because it has experienced dilution towards the earth's surface [19]. In cases where the system has a moderate fluid temperature, it may still be used as a geothermal power plant however,

Fig. 5. Temperature measurement graph on slave 1.

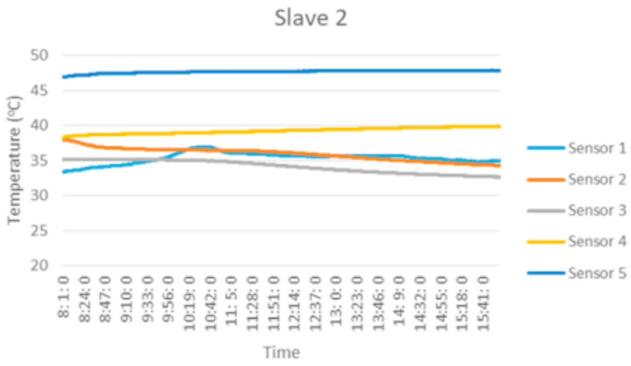

Fig. 6. Temperature measurement graph on slave 2.

Fig. 7. Temperature measurement graph on slave 3.

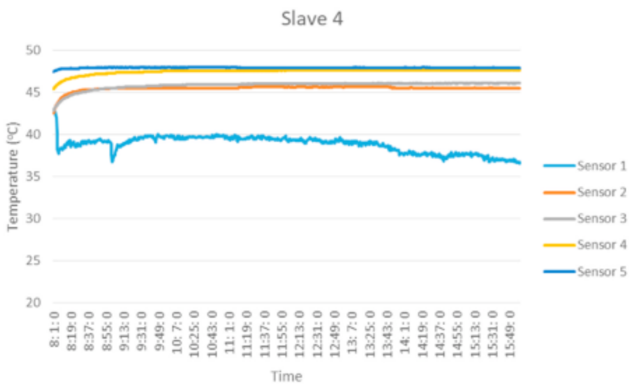

Fig. 8. Temperature measurement graph on slave 4.

Table 1
The average value of measurement results.

Sensor	Depth (m)	Slave 1 (°C)	Slave 2 (°C)	Slave 3 (°C)	Slave 4 (°C)
1	0.4	26.678	35.357	28.356	38.791
2	0.8	28.388	35.923	34.531	45.463
3	1.2	28.833	36.158	39.903	45.802
4	1.6	29.003	39.262	46.621	47.474
5	2	34.354	47.696	48.975	47.888

Table 2
Data for gradient temperature calculation.

Name	$T_{0.4}$ (°C)	$T_{0.8}$ (°C)	$T_{1.2}$ (°C)	$T_{1.6}$ (°C)	T_2 (°C)
Slave 1	26.67804	28.38853	28.83352	29.00386	34.3547
Slave 2	35.35772	35.9227	36.15763	39.26157	47.6963
Slave 3	28.35676	34.53133	39.90364	46.6205	48.9745
Slave 4	38.79039	45.46336	45.80178	47.4739	47.8881

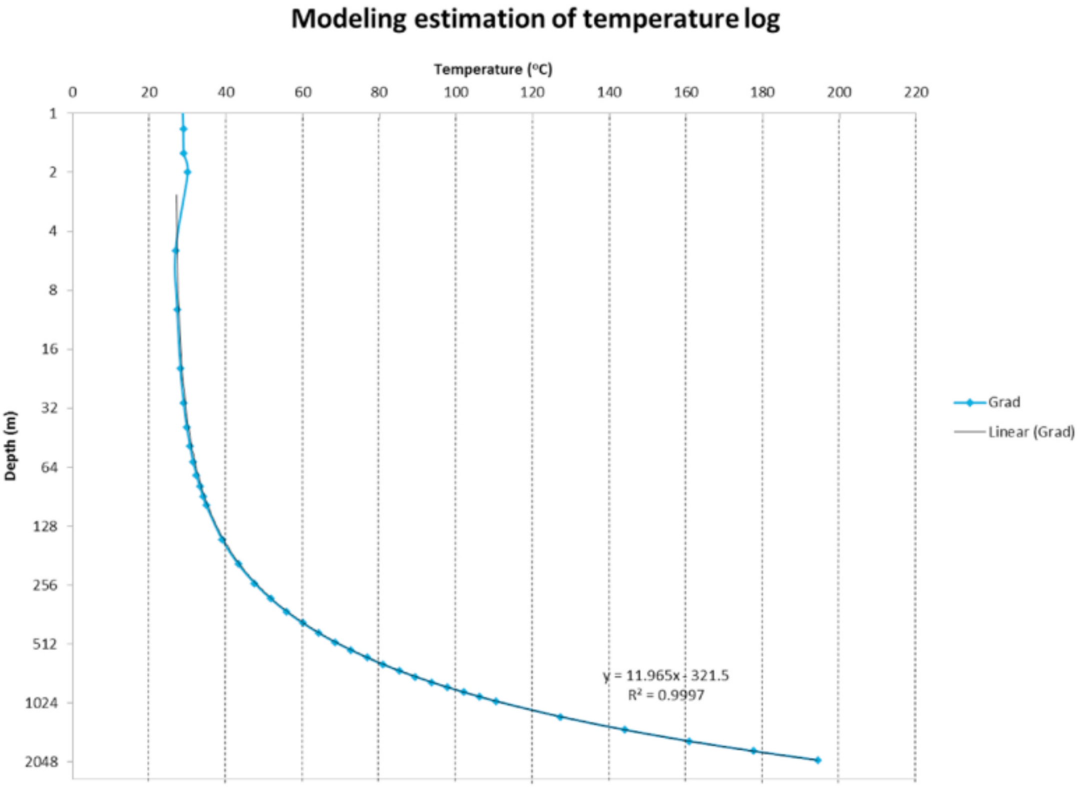

Fig. 9. Modeling estimation of temperature log.

further study is needed to utilize geothermal areas [18].

From the temperature of gradient data and equation 2, the result of the flow rate calculated in slaves 1, 2, 3 and 4 were 192.837 W/m^2, 309.046 W/m^2, 517.916 W/m^2 and 228.533 W/m^2, respectively with an average value of 312.083 W/m^2. Based on these results, it was discovered that the higher the temperature gradient value, the greater the rate of heat flow occurring at the drill point. Therefore, it may be estimated that the closer the heat source, the less heat energy needed to heat the rock by conduction. In addition to changing the temperature gradient, changes in the heat flow rate is also influenced by the sedimentation time and magnitude of the rock conductivity i.e. the greater the conductivity of the rock, the better the rock delivers heat or conductor and the smaller the conductivity of the rock, the worse the rock delivers heat or isolator.

5. Conclusion

The geothermal surface temperature sensor consists of 4 slaves, with each slave consisting of 5 sensors. Each of the sensors is able to record temperature with an interval of 30 s. Furthermore, each data read by the sensor was transmitted wirelessly to the wireless receiver and embedded in the main receiving memory. The temperature distribution of the legible data indicates that the highest temperature has been recorded. Reservoir temperature estimation models were obtained at a depth of 2000 m by 194 °C. In addition, the heat flow rate on slaves 1, 2, 3 and 4 were 192.837, 309.046, 517.916 and 228.533 W/m^2, respectively. Based on the results of the heat flow calculation, it was discovered that the higher the temperature gradient value, the higher the rate of heat flow occurring at the drill point.

CRediT authorship contribution statement

Akhmad Afandi: Conceptualization, Methodology, Writing - original draft, Project administration. **Nuraini Lusi:** Validation, Writing - review & editing. **Subono:** Data acquisition. **Siti Diah Ayu Febriani:** Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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