Subsurface Temperature Modeling using Integrated Modeling for Nuclear Reactor Site Assessment in Volcanic Zone

Bagus Endar B. Nurhandoko$^{1,2}$, Rizal Kurniadi$^1$, Elfa Fatiah$^2$, Muhammad Rizal Abda$^2$, Rio Martha$^2$, Sri Widowati$^3$

$^1$Physics Department, Faculty of Mathematics and Natural Science, Institut Teknologi Bandung
$^2$Rock Fluid Imaging Lab.
$^3$School of computing, Telkom University

Email: bagusnur@bdg.centrin.net.id

Abstract Indonesia has giant vulcanic arc that almost the largest vulcanic arc in the world. Therefore, one of the main risk for nuclear site plan is the vulcanic area. Therefore to reduce the risk, one of most safety nuclear site plant is old vulcanic area. In this paper, we propose to predict subsurface temperature profile to ensure the condition of subsurface of vulcanic zone. Geothermal heat flow is important parameter in modeling of subsurface temperature. The subsurface temperature is one of vulcanic activity parameter which very important for nuclear site plant risk assessment. The integrated modeling for predicting subsurface temperature profile is carried out by combining geothermal heat flow and subsurface profiles resulted from either seismic or gravity measurement. The finite difference of Fourier’s law is applied to surface temperature, temperature gradient, geothermal heat flow and thermal conductivity profile for producing subsurface temperature distribution accurately. This subsurface temperature profile is essential to characterize the vulcanic zone whether it is still active or inactive. Characterization of vulcanic activity is very useful to ensure or to minimize the risk of nuclear site plant in vulcanic zone. One of interesting case study of nuclear site plan in Indonesia is mount Muriah site plan, this method is useful to ensure whether mount Muriah is still active or inactive now.

1. Introduction
The site plan assessment is one of important study in nuclear plant development. The nuclear site plan assessment in Vulcanic area covers history of seismic activity $[1,2,3]$, volcanic hazards $[4]$, and geological evaluation $[5]$. Indonesia has potential hazards of volcanism and seismicity since lies on the world’s major chains of active volcanoes and has densely populated region.

Seismic hazard assessment needs the information of regional tectonics and fault characteristics properly. The successfull assessment of volcanic hazard strongly depends on quality of sub surface research such as geologic and geothermal researches. Some authors have been investigated about Muria volcano $[6,7,8,9]$. One of important study in volcanic hazard is a prediction whether any this volcano might be capable of future activity affecting the nuclear plant. The concept of an activity risk of volcano likes a
activity risk of fault. Activity risk can be used to distinguish those features whether has potential hazardous or not.

In the case of Muria Genuk complex Indonesia, the initial studies took two forms [10]. Firstly, the record of volcanism was examined by determine whether any of the volcanic centers had historical eruptive activity. The search revealed no record of eruptions from any volcano on Muria Peninsula. Secondly, the volcanoes and an area of 100 km$^2$ around the site were examined to determine whether there were any manifestations of current magmatic activity. Seismic records were examined for evidence of greater than normal seismicity. Temperature gradients of 5-6 °C per 100 m were measured in boreholes extending to depths of about 250 m near the site. These temperature gradients were considered normal for the region.

In this work, we propose a technique to obtain temperature distribution of subsurface using surface temperature measurement and temperature gradient.

2. Experimental Method

![Figure 1. The Line of temperature measurement](image)

Figure 1 shows the part of East Java map that indicate the position of temperature modeling. Spacing of modeling about 10 km. Beside temperature, thermal conductivities are measured.
The modeling uses data of temperature measured at line in East Java Basin, from northern part to southern part of East Java, similar direction with the line shown in Figure 1, the true position is around 150 km to the east from line shown in Figure 1. The temperature data and subsurface geology model beneath line shown in Figure 1 are input of subsurface temperature modeling.

The temperature data collected from water temperature from various depth of water level. The conductivity of samples are measured by ThermConduct™ which equipped by 5 sensors that they attach at sample (rock and cooper) and 2 thermal reservoirs (top and bottom) as shown in Figure 2.

Sample preparation includes coring, smoothing, dimension measurement and density measurement. Thermal conductivity measurement needs 2 samples, sample has around 3-4 centimeter in length and 3 cm in diameter.

Temperature sensors are attached at samples as shown by figure 2. The water in hot reservoir is boiled and kept temperature in constant value. The data (time and temperature) are collected via temperature sensor in real time.

The conductivity measurement uses Fourier equation as following:

\[
\frac{Q}{A} = K \frac{dT}{dz} \quad (1)
\]
\[
Q = m \cdot c \cdot \Delta t \quad (2)
\]

\(Q\) = Total caloric that pass through
\(A\) = Cross sectional area of sample
\(K\) = Rock conductivity
\(\frac{dT}{dz}\) = Gradient temperature of sample.
\(m\) = mass of cooper
\(c\) = Thermal capacity of cooper
\(\Delta t\) = temperature differentiation of cooper

The modeling uses various sample of lithologies: Carbonate (fig. 4), Clay (fig. 5), Tuff (fig. 6), Andesite (fig.7), and also sand sample.

Figure 8, 9, 10, 11, 12, 13, 14, 15 show measurement result of conductivity, we can estimate simply the value of conductivity from average points of measurement.

Subsurface temperature modeling use conductivity information which confirm with geological model and surface temperature data, flowchart of modeling is shown by figure 3.
The subsurface temperature profile can be estimated by combining surface temperature, temperature gradient, thermal conductivity, and geological model that it was related with gravity, seismic, and well data.

The forward model of temperature distribution is carried out thru Fourier Law which solved numerically by finite difference.

![Flow chart data processing of subsurface temperature distribution](image)

**Figure 3. Flow chart data processing of subsurface temperature distribution**

### 3. Results and Discussion

Subsurface geology model is carried out by gravity modeling constraint by geology map and well information.

Figure 4 shows lithology model resulted from gravity modeling which adjusted by considering information from geological map and wells. Colors in figure 4 indicate dominant lithology. This information of lithology is tabulated in table 1.

Intrusion rock is shown in northern part where position of Mt. Muriah, in the middle part the thrust fault creates uplift of basement. Mt. Lawu shows anomaly due of Bouguer anomaly is negative which indicates relatively low density. This anomaly may be correlated by lithology of crater whether dominated by sand and boulder or fractured lithology.

![Subsurface geology model beneath line of figure 1 by gravity modeling](image)

**Figure 4. Subsurface geology model beneath line of figure 1 by gravity modeling.**
Table 1. Density of rocks formation

| Color | Formation                  | Delta Density | Density |
|-------|----------------------------|---------------|---------|
| Red   | Quarter Vulcanic           | 1.07          | 3.4     |
| Purple| Basement                   | 0.54          | 2.87    |
| orange| Volcanic Lawu              | -0.22         | 2.11    |
| Purple| Eosen-Oligosen sediment    | 0.27          | 2.6     |
| Yellow| Miosen sediment            | 0.07          | 2.4     |
| Green | Plio-Plistosen Sediment    | -0.46         | 1.87    |

Table 2. The tabulation of “dummy” surface data

| Daerah       | Position (Km) | Temp °C | Gradient (°C/ 100 m) | Temp Correction °C |
|--------------|---------------|---------|----------------------|--------------------|
| Mlonggo      | 0             | 30.48   | 5.5                  | 31.52              |
| Brati        | 55            | 30.74   | 3.6                  | 31.06              |
| Purwodadi    | 70            | 29.64   | 3.7                  | 29.97              |
| Gendingan    | 100           | 29.9    | 3.78                 | 30.05              |
| Sragen       | 105           | 29.92   | 2.7                  | 30.51              |
| Magetan      | 135           | 29.79   | 2.05                 | 29.95              |
| Jatiroto     | 155           | 29.1    | 2.5                  | 29.45              |

Figure 4. Carbonate sample
Figure 5. Clay sampel

Figure 6. Tuff Sampel

Figure 7. Andesit

Figure 8. Carbonate Heatflow

Figure 9. Clay Heatflow
Figure 10. Tuff Heatflow

Figure 11. Andesit Heatflow

Figure 12. Carbonate thermal conductivity

Figure 13. Clay thermal conductivity
Thermal conductivity (K) of material is a unique property. From the results, K value is increasing due to increasing of mass density. High density rock has small pores hence there are small volumes of fluid in the rock. Because of small amount of fluid, the heat is easier to be transferred.

Figure 16 shows subsurface conductivity model calculated based on geology model from gravity modeling as shown by Figure 4.

By combining conductivity model of Figure 16 and surface temperature data including geothermal heat flow, the subsurface temperature profile can be resulted as shown by Figure 17.
4. Conclusions
1. The input data for subsurface temperature profiling are surface temperature, temperature gradient, conductivity of rock and subsurface geology modeling. The subsurface geology model is calculated from gravity modeling which constraint by surface geology, well data and seismic.
2. The proposed heatflow measurements as well as subsurface temperature profiling can provide robust estimation of subsurface temperature profile.
3. The subsurface temperature profile represents condition of sub-volcanic zone for determining the activity of volcanic zone. It is very important for nuclear site plan assessment.

Acknowledgments
This research is fully supported by Indonesian ministry of education research grant and Rock Fluid Imaging Lab.

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