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Comparison of Geothermal Reservoir Characteristics, Geothermometers, and Heat Loss in Sukarame, West Java Region with Banjarnegara, Central Java Region Based on Geochemical Data Analysis

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Abstract. Banjarnegara and Cisukarame are potential areas for geothermal development. This research was conducted to obtain geothermal fluid characteristics, reservoir temperature, geo-thermometer and heat loss. Reservoir temperature is determined based on geothermometer calculations of Na-K-Ca, K-Na-Mg and Na-K. This type of manifestation like hot springs, it can be used to calculate the amount of heat loss. There are four geothermal reservoirs in the Banjarnegara area. Based on the analysis of the geothermometer value, reservoir 1 until 4 temperature is around 81°C - 374°C, the heat loss value reaches 31.6 MW. Beside it, in Cisukarame areas, the highest value of geothermometer temperature average 185°C - 212°C, the heat loss value obtained 48.3 MW. Heat loss value is used to determine the geothermal potential for build prospect power plant. Thus, a more efficient ratio of temperature and heat loss value is Cisukarame area, but both of them are potential for geothermal power plants development.

Keyword: Geothermal, Cisukarame, Banjarnegara, Geothermometers, Heat loss)

1. INTRODUCTION

Geothermal is one of the renewable energy in the world. Subsurface hydrogeochemical conditions can be analysed well through manifestations, for example hot springs and oil are changed (Hochstein and Browne, 1994^[4]). Manifestation is one of the characteristics of the meaning of geothermal. Geothermal energy appears in various forms of manifestation such as warm soil, steamy soil, hot / warm air eyes, hot air ponds, hot air ponds, fumaroles, geysers, hot mud puddles, sintered silica and interlaced rocks (Saptadji, 2003^[7]).

Indonesia has many volcanic and non-volcanic geothermal sources which number 276 locations. One



area that has geothermal potential is Cisukarame, Sukabumi and Banjarnegara Districts. Basically, Banjarnegara Regency is known for its Dieng geothermal field which produces energy with a proven capacity of 60 Mw. PT Geo Dipa Energi has been working on this geothermal energy which has been sold to PLN and has been integrated into the Bali Madura Java interconnection system (Pohan, et al, 2008^[6]). Meanwhile the manifestations of geothermal hot fluids in Banjarnegara are found in 8 locations. Water that appears on the surface can be used to determine subsurface conditions. The functional of this hydrochemical data for the prospecting stage is useful to obtain information about: reservoir type, reservoir temperature, rock type, magnitude of heat flow, areas that have high heat flow, environmental problems, filling areas, determination of the location of exploration wells. Meanwhile, Cisukarame area has a manifestation such as steam ground and hot spring. In that area, it has 8 manifestation research point.

The concentration of the elements can also be used to estimate the temperature of the reservoir or the temperature of the water source below the surface. Type of Geotermometer, including silica, sodium – potassium, sodium – calcium – potassium.

2. METHODS

The method used in this research is by using geomorphological analysis method, concentration of element analysis based on the theory of Fournier (1979)^[3] and Giggenbach (1988)^[2], Geotermometer, Heatloss based on Hochstein's theory (1994)^[4], the origin of fluids and the characteristics of geothermal reservoirs based on theory (Nicholson, 1993)^[5], the temperature reservoir in the study area.

<div style="margin-bottom: 10px;">1217</div> <div style="display: flex; justify-content: space-between;"> $T (^{\circ}\text{C}) = \frac{\text{Log (Na/K)} + 1.483}{0.0122} - 273$ (Fournier, 1979) </div>
<div style="margin-bottom: 10px;">1390</div> <div style="display: flex; justify-content: space-between;"> $T (^{\circ}\text{C}) = \frac{\text{Log (Na/K)} + 1.75}{0.0166} - 273$ (Giggenbach, 1988) </div>
<div style="border: 1px solid black; padding: 5px; margin: 10px auto; width: 80%;"> $Q = m \cdot (hfT - hfT_0) = m \cdot c \cdot (T - T_0)$ <p style="text-align: center;">Hochstein (1994)</p> </div>

3. RESULT AND DISCUSSION

3.1 Regional of Geology

The Banjarnegara geothermal area is in the Jembangan Volcanics formation with the lithology of Andesitic lava volcanoclastics. Predominantly, augite-hypersthene andesite containing hornblende in places as well as olivine basalt. Present as lava flow, flow and pyroclastic breccia, lava and alluvium (Qjo and Qjm)^[1] lava flow and alluvium consists of volcanic debris, deposited lava flow and breccia (Qjya and Qjma) in a gentle slope, and slightly far from eruption centers compared to Qjf and Qjmf comprising lava flow and breccia and pyroclastic breccia and lava. Meanwhile, Cisukarame Geothermal Area is composed by Citarate formation, Cimapag formation and occur tectonic activity make a fold and dacite intrusion, and be covered by Cimanceuri formation and occur uplift and fault, andesit intrusion, and covered by vulcanik quarter deposit. The intrusion effect is assume that it can be a heat source.

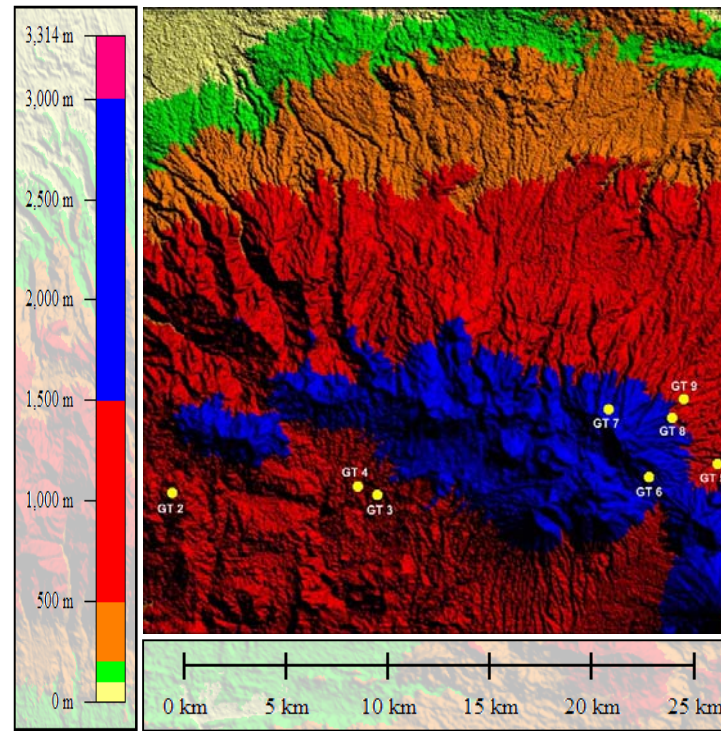


Figure 1. Morphography Map Banjarnegara Area

Based on the morphographic map of Banjarnegara area analyzed from the DEM map (Digital Elevation Mode) obtained at least 5 geomorphological units referring to the Van Zuidam 1985 classification, namely, lowland with light green index, low hills with green index, hills with orange index, high hills with red and mountainous indices with blue indexes. And found in the study area there are at least 8 geothermal manifestations in the form of hot springs, which are divided into 2 geomorphological units, namely high hills with the location of GT-2, GT-3, GT-4, GT-5, GT-9 and mountains with locations GT-6, GT-7, GT-8, elevation greatly affects the Heat loss the higher the elevation, the higher the heat loss. From the data we get, the GT-2, GT-3, GT-4, GT-5, GT-9 have lower Heat loss values than the GT-6, GT-7, GT-8.

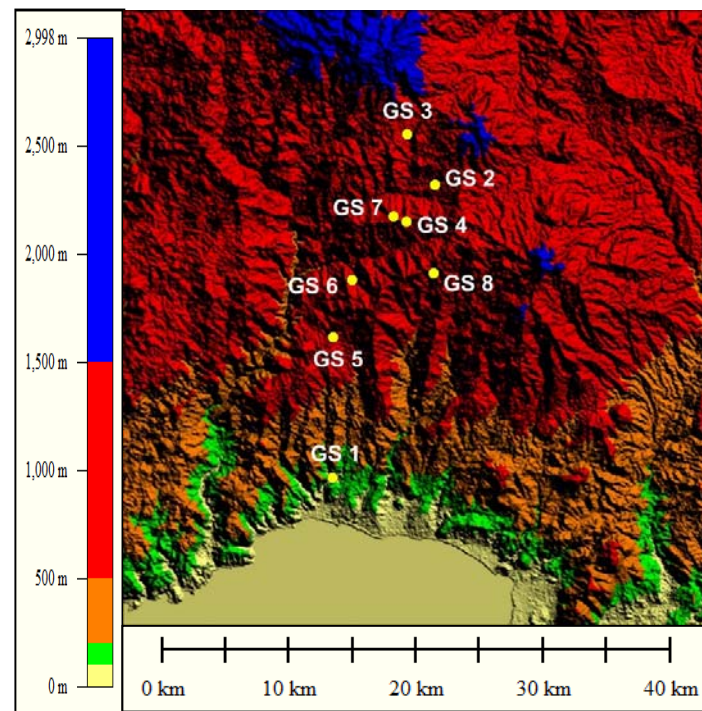


Figure 2. Morphography Map Cisukarama Area

Based on the morphographic map of the Cisukarama area analyzed from the DEM map (Digital Elevation Mode) obtained at least 4 geomorphological units referring to the Van Zuidam 1985 classification, namely, low hills with green indexes, hills with orange indexes, high hills with red and mountainous indices with a blue index. And found in the study area there are at least 8 locations of geothermal manifestations in the form of hot springs, which are divided into 2 geomorphological units namely low hills and hills, elevation greatly affects the Heat loss the higher the elevation, the higher the heat loss. From the data we get, GS-1 has the lowest Heat loss value.

Geothermal manifestations in the Cisukarama area, there are hot springs, hot water pools, and steaming ground. In this case, hot springs in the area form hot water pools above andesite rocks and are covered by alluvial deposits with temperatures around 54°C - 99°C with a pH ranging from 6.8 - 8.2. Meanwhile, the geothermal manifestations found in the banjarnegara area are in the form of hot springs with a pH of about 7, with the temperature being in the range of 39°C - 87°C.

Manifestations of geothermal hot fluid in Banjarnegara region are found in 8 locations. Water sampling was carried out in nine geothermal manifestation locations in Banjarnegara District. The sampling locations are in Gumelem-Susukan Village (GT-1), Kalibening (GT-2), Tempuran-Wanayasa (GT-3), Kaliputih-Wanayasa (GT-4), Sikidang-Batur Crater (GT-5), Pulosari-Batur (GT-6), Candra Dimuka Crater (GT-7), Sileri Crater (GT-8) and Bitingan-Batur (GT-9). The results of the hydrochemical analysis can be seen in Table 1. Based on the results of the hydrochemical analysis then the calculation of the equations of the cations and anions is carried out to check whether the results of the analysis are good or not. Surface water is used to determine reservoir type, reservoir temperature, rock type, amount of heat flow, area with high heat flow, determination of drill point.

3.2 Characteristic Element of Geothermal Manifestation

Geochemical data of geothermal is obtained based on the calculation of the concentration of the contained elements such as bicarbonate, chloride, and sulfate. This uses geothermometer analysis. Based on geothermometer data in the study area, the percentage of data is obtained as follows:

Location	%Cl	%HCO ₃	%SO ₄
GS-01	50.15	32.08	17.77
GS-03	56.99	25.82	17.19
GS-04	64.83	15.98	19.19
GS-05	64.17	16.94	18.89
GS-06	68.31	11.93	19.76
GS-07	63.68	17.30	19.02
GS-08	68.30	12.03	19.67
GS-02	40.22	43.84	15.94

Table 1 Concentration of Element Percentage Cl, SO₄ dan HCO₃ (Cisukarame)

From the table data, it can be seen that there are seven location points that contain concentrations of Cl elements including GS-09, GS-11, GS-12, GS-13, GS-14, GS-15, GS-16, meanwhile GS-10, GS-17 contains the dominance of HCO₃ elements.

Location	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)
GT-1	1412.51	0.79	16.47
GT-2	86.67	1.21	885.53
GT-3	639.34	0.00	982.08
GT-4	538.46	0.00	1288.90
GT-5	2.64	996.12	0.00
GT-6	426.01	75.08	153.76
GT-7	4.34	895.42	60.66
GT-8	26.49	276.53	298.79
GT-9	10.98	73.82	361.45

Table 2 Concentration of Element Percentage Cl, SO₄, dan HCO₃ (Banjarnegara)

Meanwhile in the Banjarnegara area, the sampling location is in Gumelem-Susukan Village (GT-1), Kalibening (GT-2), Tempuran-Wanayasa (GT-3), Kaliputih-Wanayasa (GT-4), Sikidang-Batur Crater (GT-5), Pulosari-Batur (GT-6), Candra Dimuka Crater (GT-7), Sileri Crater (GT-8) and Bitingan-Batur (GT-9). Geothermal fluid types in Banjarnegara include Chloride (GT-1 and GT-6), Bicarbonate (GT-2, GT-3, GT-4, GT-8 and GT-9) and Sulphate (GT-5 and GT-7). The type of bicarbonate fluid (peripheral water) indicates a mixture with ground water. While chloride water (mature water) indicates that the water source comes

from the reservoir, while sulphate water (volcanic water) indicates that the water source is related to volcanism (Nicholson, 1993)^[5]

3.3 Geothermometer of Geothermal in Cisukarame and Banjarnegara

Calculation of Na/K geothermometer can be done using several empirical equations, among others, based on the theory of Fournier (1979)^[3] and Giggenbach (1988)^[2], with the equation:

$$T (^{\circ}\text{C}) = \frac{1217}{\log\left(\frac{\text{Na}}{\text{K}}\right) + 1.483} - 273 \text{ (Fournier, 1979)}$$

$$T (^{\circ}\text{C}) = \frac{1390}{\log\left(\frac{\text{Na}}{\text{K}}\right) + 1.75} - 273 \text{ (Giggenbach, 1988)}$$

Based on the use of the empirical formula, it is better not to use this equation in conditions of water with low chloride content or in water containing Na-HCO₃ or water, HCO₃ or ammonia-rich water that has reacted with sediments rich in organic matter (Sumintadireja A P , 2005^[8]). Therefore, the equation is calculated based on the location of GS 01, GS 03, GS 04, GS 05, GS 06, GS 07, and GS 08 then obtained a calculation table for Na / K geothermometers, including:

Sample	Geothermometer Na-K	
	Fornier, 1979	Giggenbach, 1988
GS 01	197	213
GS 03	194	211
GS 04	192	209
GS 05	185	202
GS 06	188	205
GS 07	195	212
GS 08	195	212

Table 3. Geothermometer Na/K

It can be seen that the Cisukarame geothermal geothermometer ranges from 185°C - 197 ° C (Fornier, 1979) or 202 ° C - 213 ° C (Giggenbach, 1988)^[2]

Sample	Geothermometer Na-K	
	Fornier, 1979	Giggenbach, 1988
GT 01	174	81
GT 06	137	-
GT 02	264	276
GT 04	222	237
GT 04	232	246
GT 08	334	339
GT 09	374	374

Table 4. Geothermometer Na/K

It can be seen that the Banjarnegara geothermal geothermometer ranges from 137°C - 374°C (Fornier, 1979) or 81°C - 374°C (Giggenbach, 1988)^[2].

3.4 Geothermal Heatloss in Cisukarame and Banjarnegara

Calculation of natural heat loss in determining geothermal potential needs to be done at the geothermal manifestation output in the study area. This natural heat loss is calculated based on the formula given by Hochstein (1994)^[4],

$$Q = m \cdot (hfT - hfT_0) = m \cdot c \cdot (T - T_0)$$

Hochstein (1994)

Natural heat loss calculations are adjusted to the type of geothermal manifestation. The above formula can be used for direct output, namely hot or warm springs, flow of hot water, fumarole and steam coming out of fractures. Natural heat loss calculations will be performed for manifestations of hot and warm springs.

No	Research Point Area	Debit	C	Temperature Udara (T ₀)	Temperature Fluida (T ₁)	ΔT T ₁ - T ₀	Q
1	GT-1	1.53	4.20	27	41.9	14.9	95.55
2	GT-2	16.75	4.20	25	42.6	17.9	1238.37
3	GT-3	50.18	4.20	24	39.5	15.5	3266.98
4	GT-4	2.29	4.20	24	43.4	19.4	186.24
5	GT-5	0	4.20	18	87.2	69.2	0.00
6	GT-6	1.57	4.20	20	57.4	37.4	246.40
7	GT-7	0	4.20	22	84	62	0.00
8	GT-8	37.46	4.20	22	59.6	37.6	5915.50
9	GT-9	115.23	4.20	22	64.7	42.7	20664.94
Total(MW)							31.61398

Table 5. Heat Loss Date Banjarnegara Area

No	Research Point Area	Debit	C	Temperature Air (T_0)	Temperature Fluida (T_1)	ΔT $T_1 - T_0$	Q
1	C-09	0.7	4.20	27	54.2	27.2	79.968
2	C-10	1.78	4.20	25	99.4	74.4	556.2144
3	C-11	5.75	4.20	24	97.7	73.7	1779.855
4	C-12	0.3	4.20	23	98.7	75.7	95.382
5	C-13	62.5	4.20	24	99.6	75.6	10319.4
6	C-14	52.5	4.20	20	98.9	78.9	7456.05
7	C-15	85.3	4.20	24	99	75	18900
8	C-16	7.3	4.20	23	53.6	30.6	938.196
9	C-17	35.7	4.20	22	97.6	75.6	8160.264
Total(MW)							48.28533

Table 6. Heat Loss Date Cisukarame Area

4. CONCLUSION

1. Cisukarame geothermal manifestation is located along the Cisukarame river in the form of steaming ground and hot springs as many as 8 manifestation points, while in the banjarnegara area has 8 manifestation points which are generally in the form of hot springs.
2. Geothermometer calculation from geochemical analysis results shows the reservoir temperature in the cisukarame area ranges from 185°C-212°C so that the geothermal field is included in the classification of the medium enthalpy geothermal system, meanwhile the reservoir temperature in the banjarnegara area ranges from 81°C - 374°C so that this geothermal field is included in the classification of the high enthalphi geothermal system.
3. In the Cisukarame area, there are 7 manifestation points with types and characteristics in the form of Chloride (Cl) fluid including C-09, C-11, C-12, C-13, C-14, C-15, C-16, while C-10, C-17 is a type of bicarbonate fluide (HCO_3). Meanwhile in Banjarnegara area, geothermal fluid types in Banjarnegara include chloride (GT-1 and GT-6), Bicarbonate (GT-2, GT-3, GT-4, GT-8 and GT-9) and Sulfate (GT - 5 and GT-7)
4. The heat loss of the prospect of the Cisukarame geothermal field is 48.28533 MW, while the heat loss of the prospect of the Banjarnegara geothermal field is 31.61398 MW.

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