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Isotope and Gas Geochemistry of Dieng Geothermal Field, Indonesia

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ABSTRACT

Gas and isotope samples of geothermal fluid has been taken from Dieng geothermal field, namely HCE-7A, HCE-7B, HCE-7C, HCE-28A, HCE-28B and HCE-31 in two periods of sampling. The gas samples were determined for H_2, He, N_2, O_2, Ar, CH_4, CO_2 and H_2S content by chromatographic method. Whereas isotope samples were analyzed for ^{18}O and ^{2}H ratio from H_2O and ^{13}C ratio from CO_2 by mass spectrometer. Gas analysis results from two periods of sampling shows varied values that indicate the dynamics of reservoir's fluid. The interpretation of N_2, Ar composition and also isotopic ratio of ^{18}O and ^{2}H clearly indicate that the fluid is meteoric origin and has been experienced intense water – rock interaction in high temperature, although there is possibility of magmatic contribution. Isotopic ratio of ^{13}C shows that CO_2 of Dieng geothermal fluid is magmatic origin. More interpretation of gas composition shows that the temperature of reservoir are ranged between 240°C to 333°C, and some part of it has boiling process and vapor loss.

1. INTRODUCTION

The development of geothermal energy both in exploration stage and exploitation stage is a challenging task, covering various areas of science such as geology, geophysics, geochemistry and engineering. During the exploitation of geothermal energy, detailed understanding of reservoir is a must so that a geothermal field can achieve sustainable production.

Geochemistry technique, particularly gas and isotope geochemistry, is a technique that can be applied as a tool to asses the sub surface temperature, steam fraction, mineral equilibrium and other physical processes in the reservoir such as boiling and mixing, using chemical and isotope data (Arnorsson, 2000). In this paper, isotope and gas geochemistry methods are used to evaluate the liquid dominated reservoir system, in Dieng geothermal field which includes the sub surface temperature (geothermometer), steam fraction and physical process in reservoir.

2. METHOD

2.1 Dieng geothermal field

Dieng geothermal filed is located in Central Java and it represents the two phase reservoir liquid dominated phase (fig 1). The Dieng mountain complex is composed of Quaternary volcanic rocks aligned similarly as to the regional structural features. The E-W trend extends from Gunung Butak on the west to Gunung Prau on the east. The peaks of these mountain complex rise to elevations between 2200 to 2555 masl. The surface rocks in this area are covered by quaternary andesite lava flows and pyroclastic units (van Bergen, et.al., 2000).

The field has installed capacity of 60 MW electricity supplied by its 8 production wells namely HCE-7A, HCE-7B, HCE-7C, HCE-9A, HCE-9B, HCE-28A, HCE-28B and HCE-31. But at the time of sampling, HCE-9A and HCE-9B wells were closed, so the sampling was done only for other six wells.

2.2. Sampling

The fluids were taken using Weber separator connected to the side valve in the wellhead (whenever possible) or in the pipeline to separate the vapor phase (gas) and liquid phase. Sampling is conducted in a constant pressure. The gas sample is taken using evacuated bulb contains 4 N NaOH solution. Fluid containing water vapor (condensable gas) and non-condensable gases such as CO_2 and H_2S are dissolved in NaOH, whereas the non reactive gases such as H_2, He, Ar, N_2 and CH_4 will occupy the head space above NaOH solution. In addition for isotope sample, a condenser is attached into Weber separator and the condensed fluids were collected in 20 mL plastic bottle.

2.3. Analysis of samples

Non-reactive gases such as H_2, He, Ar, N_2 and CH_4 were done with gas chromatography using Perkin-Elmer GC equipped with Arnell injection system. The column used in gas analysis is Porapak. For analysis of H_2 and He, N_2 gas is used as carrier gas, while Ar, N_2 and CH_4, He is used as carrier gas. Both gas analyses are performed simultaneously using two thermal conductivity detectors (TCD). For CO_2 and H_2S analysis, titrimetric method is used. Ratio of ^{18}O isotope is determined using equilibration with the CO_2 standard, while for ^{2}H isotope is using zinc reduction method. Whereas ^{13}C analysis was prepared using $BaCO_3$ precipitation method. All isotope ratios were analyzed by using SIRA-9 mass spectrometer.

3. RESULTS

3.1. General description

Gas analysis result can be seen in table 1. Results are expressed in units of mmol/kg of steam. The table shows that the gas concentrations between the two sampling periods were not significantly different.

Meanwhile, the value of discharge steam fraction were varied between 29% to 45%, with the lowest steam fraction was found in HCE-7B well, while the highest in HCE-7C well. Another thing that can be seen from the results of the analysis is the concentration of gas in the fluid which was taken in different separator pressure separator did not affect the results of the analysis. Fluid from HCE-7A was taken in different separator pressure i.e. 10 bar and 12 bar, yet the gas concentration did not indicate a significant difference.

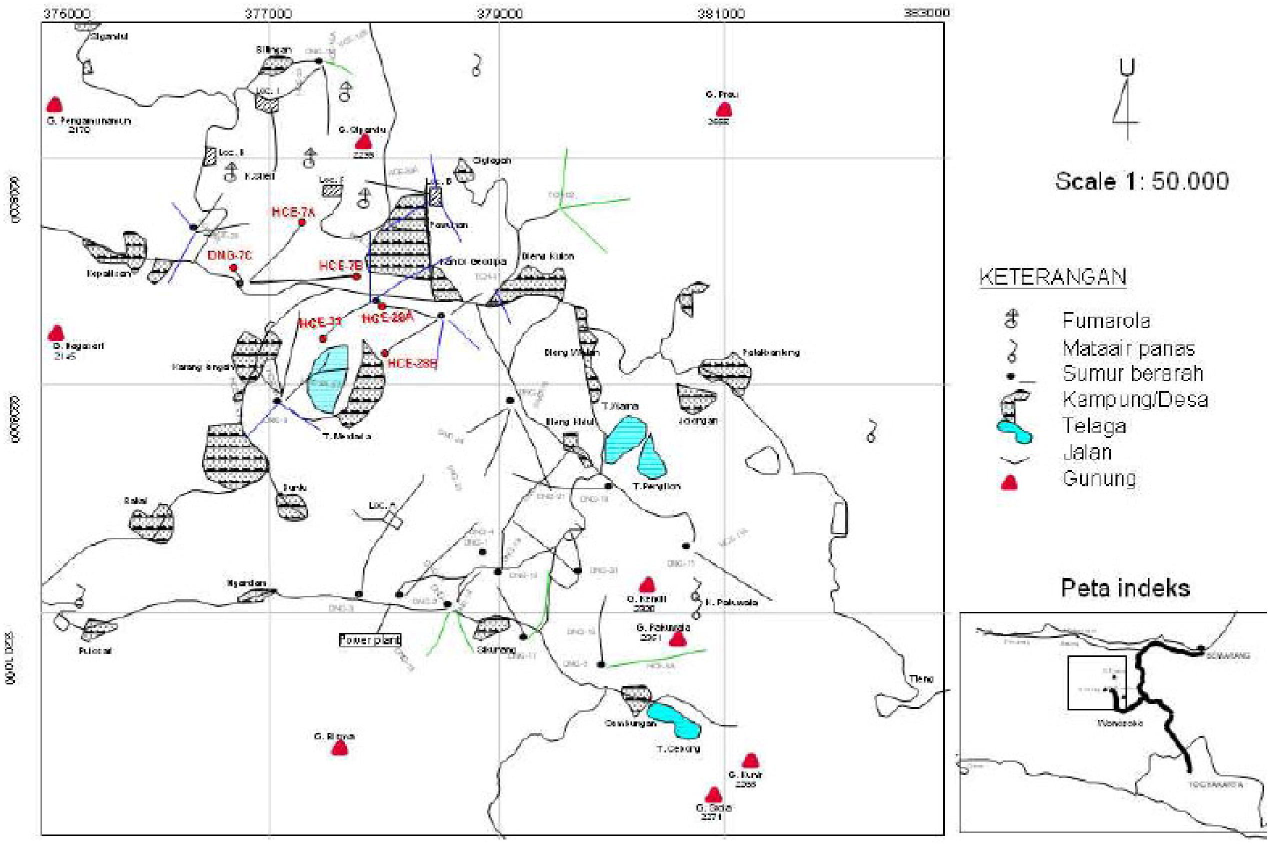

Figure 1. Location of Dieng geothermal field.

3.2. Steam fraction

FT – HSH method was used to evaluate the steam fraction of reservoir (y), which first developed by D'Amore and Celati (D'Amore, F., Celati, R., 1983). This method is based on Fischer – Tropsch reaction (methane breakdown) and also pyrite - magnetite equilibrium. Figure 2 shows the FT – HSH grid diagram of Dieng geothermal fluid.

At the first sampling period, the entire sample show positive value of y, except in HCE-28B which has a value of -0.07. The negative value of steam fraction indicates a boiling process and steam loss. This is confirmed with a low ratio of CO_2/H_2S, because the CO_2 is less soluble and removed from the liquid phase. In the second sampling, HCE-7B and HCE-31 nave negative value of y, i.e. -0.022 and -0.15. The graph also shows that in the first sampling the temperature of reservoir range between 300 - 350^oC, except in the HCE-29A that reached 370^oC, while for the second sampling the temperature range between 325 - 350^oC except for HCE-7B that below 300^oC.

Both temperature and y of HCE-7A and HCE-7C were increase during the two sampling periods. These phenomena might be caused by lateral input of steam that mixed with the original fluid. Meanwhile, increasing temperature and decreasing y in HCE-31 indicate a contribution from deeper and hotter heat source thus triggering vapor loss (D'Amore, et.al., 1993).

3.3. Gas geothermometer

Summary of the geothermometer can be seen in table 2. The table shows that the reservoir temperature varies between 195 - 418^oC. However, H_2/Ar geothermometer shows unrealistic value because it spread widely from 195^oC to 418^oC and also often has different value compare to other geothermometer. Ar is an inert atmospheric gas that the solubility in vapor phase depends only in its distribution coefficient and temperature, while H_2 is a reactive gas that can also react with minerals in the reservoir. This geothermometer result shows that Ar and H_2 species were not in equilibrium state, so that this geothermometer can not be applied in the system.

3.4. Origin of fluid

The origin of fluid can be evaluated using the triangular diagram of He, N_2 and Ar, as shown in figure 3. The triangular diagram shows that Dieng geothermal fluid is meteoric origin. This result also confirmed by isotope analysis result.

3.5. ^{2}H, ^{18}O and ^{13}C isotopes

Analysis result of ^{2}H, ^{18}O and ^{13}C isotopes can be seen in table 3. The table shows that the value of the ^{18}O is strongly enriched, ranged between 3.13 - 4.68 $^o/_{oo}$. Whereas the value of ^{2}H ranged between -38$^o/_{oo}$ to -49.6$^o/_{oo}$ which is inside the range of Dieng meteoric water, i.e. between -36.8 $^o/_{oo}$ to -62.5$^o/_{oo}$ with the average value of -47.08$^o/_{oo}$ and local meteoric line equation as follow (BAFI-BATAN, 1990):

$$\delta^2H = 7.85\ \delta^{18}O + 16.5 \qquad .... (1)$$

Figure 3 shows the relationship between ^{18}O and ^{2}H of Dieng geothermal fluids and also the local meteoric line. The graph shows that the "oxygen shift" is very high, up to 12$^o/_{oo}$. In comparison, the Lahendong, North Sulawesi geothermal fluids were only ranged between -4.84 $^o/_{oo}$ to -5.25 $^o/_{oo}$ (PATIR – BATAN, 2005),.

In addition to highly enriched, the value of ^{18}O Dieng geothermal fluids also plotted near the value of magmatic ^{18}O. There are two possibilities that might cause this highly enriched fluid, where both possibilities can occur simultaneously. The first possibility is the intensity of water - rock interaction at very high temperature with a very long transit time in the reservoir. But this possibility is very limited since the oxygen isotope can hardly shift about $7^{o}/_{oo}$ at 350°C (O Neil, J.R., Taylor Jr., H.P., 1967).

The second possibility is there was mixing process between reservoir fluids with magmatic water. However, this mixing process is difficult to quantify, because the original value of ^{18}O isotope was not known.

Compared with the exploration data of Dieng geothermal field which has oxygen shift varied between 3 - $10^{o}/_{oo}$, the current ^{18}O value shows the effect of reservoir exploitation. It is possible that there was a slow recharge mechanism into reservoir so that the value of ^{18}O was more enriched.

Meanwhile, the ^{13}C isotope ratio of CO_2 is ranged between $-2.78^{o}/_{oo}$ to $-6.44^{o}/_{oo}$ with the average value of $-4.68^{o}/_{oo}$. This value is similar with the typical value of magmatic CO_2 and also crustal carbonates (Clark, I., Fritz, P., 1997). This also indicates that the reservoir fluids had experience mixing and interaction with magmatic fluid, as also shown by ^{2}H and ^{18}O data. The latter possibility, crustal carbonate derived, is not likely happened because the carbonate minerals in this field are not common.

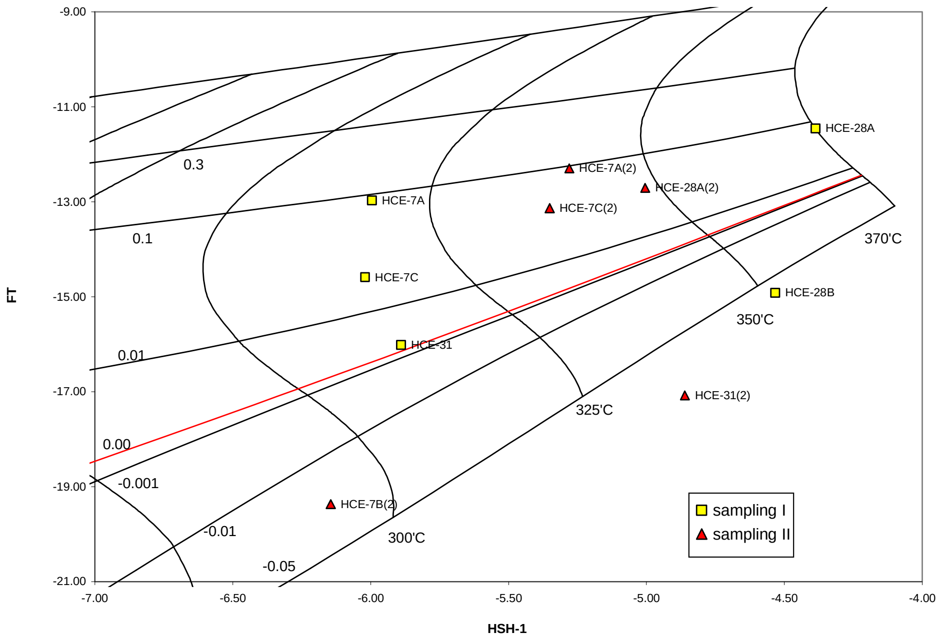

Figure 2. FT-HSH diagram of Dieng geothermal fluid.

Table 1. Gas compositions of Dieng geothermal field (mmol/kg steam).

No.	Production well	Discharge steam fraction	CO_2	H_2S	H_2	N_2	O_2	Ar	CH_4
	First sampling :								
1	HCE-7A 12 bar	0.34	257.122	18.303	5.688	0.278	0.000	0.004	3.685
2	HCE-7A 10 bar	0.35	268.711	17.987	6.517	0.277	0.000	0.005	3.925
3	HCE-7B	0.29	5.252	1.154	0.000	0.358	0.002	0.006	0.025
4	HCE-7C	0.45	219.981	9.824	1.567	0.380	0.002	0.024	1.282
5	HCE-28A	0.38	188.779	51.407	7.434	0.367	0.000	0.002	0.823
6	HCE-28B	0.34	10.525	10.953	0.125	0.007	0.000	0.001	0.000
7	HCE-31	0.35	70.192	6.061	0.470	0.017	0.001	0.002	0.263
	Second sampling:								
1	HCE-7A	0.37	307.483	23.389	5.894	0.324	0.004	0.062	4.259
2	HCE-7B	0.31	15.103	2.443	0.070	2.696	0.002	0.081	0.100
3	HCE-7C	0.45	511.420	21.962	3.736	1.331	0.001	0.066	3.334
4	HCE-28A	0.38	126.454	24.749	3.438	0.265	0.003	0.029	0.450
5	HCE-31	0.36	54.840	10.217	0.194	0.118	0.000	0.026	0.057

Table 2. Gas geothermometer calculation

Wells	Geothermometer (°C) T1	T2	T3	T4	T5	T6	Remarks
First sampling:							
HCE-7A	269.4	295	391.8*	318	245*	290*	
HCE-7C	237.5*	280.4	231.8*	316	260	300	
HCE-28A	324.5	301.6	418.4*	370*	220*	330	
HCE-28B	303.9	286.7	333.1	351	245*	380*	T_1 = D'Amore - Panichi geothermometer (D'Amore, F., Panichi, C., 1980)
HCE-31	249.2*	279.6	345.4*	313	275	320	T_2 = CO_2/H_2 geothermometer (Arnorsson, S., Gunlaugsson, E., 1985)
Second sampling:							
HCE-7A	265.5	292.6	348.2*	341*	225*	285	T_3 = H_2/Ar geothermometer (Arnorsson, S., Gunlaugsson, E., 1985)
HCE-7B	242.2	275	195.5*	393*	220	230	T_4 = FT-HSH method (Arnorsson, S., D' Amore, F., 2000,)
HCE-7C	236.6*	280.7	297.5	337*	260	298	T_5 =H_2-Ar-CH_4 (Giggenbach, W.F., and Goguel, R.L., 1989)
HCE-28A	307.4	297*	351.7	348	210*	325	T_6 = H_2-Ar-CH_4-CO_2 geoindicator (Giggenbach, W.F., 1993)
HCE-31	254.1	271.6	263.7	337*	270	290	

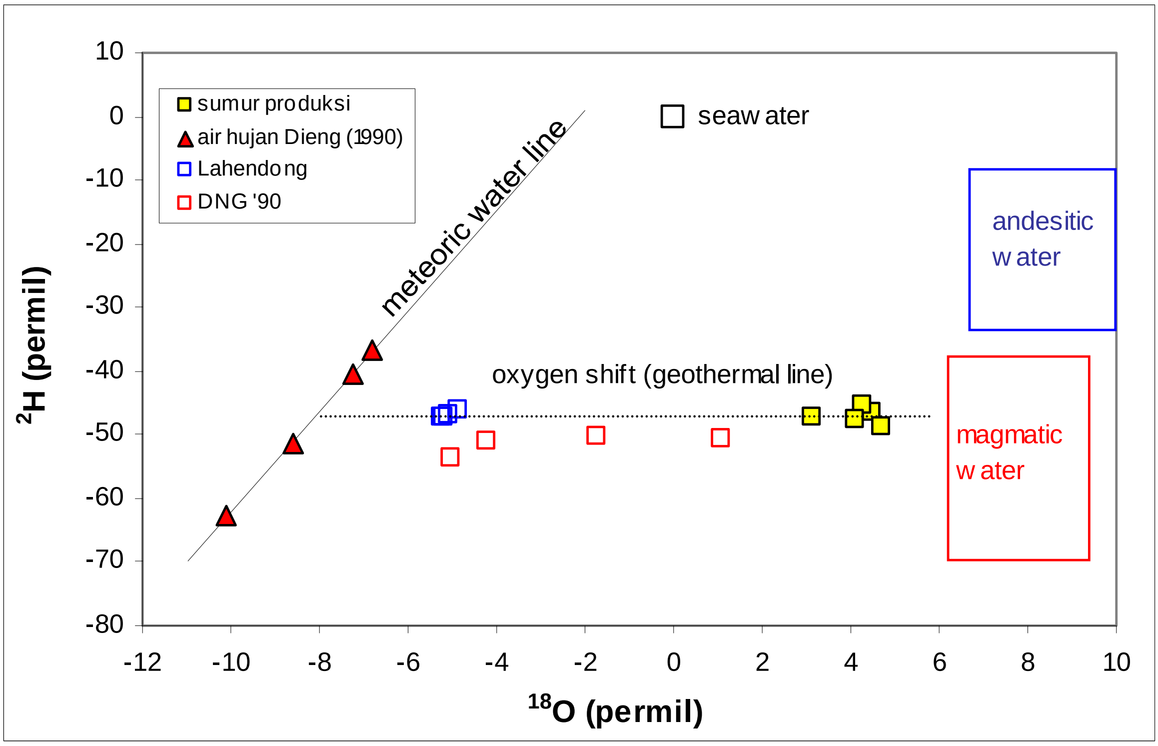

Figure 3. ^{18}O versus ^{2}H isotope of Dieng geothermal field.

Table 3. Isotope ratio of Dieng geothermal field (°/oo).

Wells	H_2O (vs SMOW) ^{18}O	^{2}H	CO_2 (vs PDB) ^{18}O	^{13}C
HCE-7A	4.48	-46.6	10.79	-4.09
HCE-7B	4.09	-47.5	-	-
HCE-7C	3.13	-47.2	-2.78	-2.78
HCE-28A	3.78	-38.0	3.54	-6.44
HCE-28B	4.68	-49.6	44.84	-6.41
HCE-31	4.26	-42.5	-0.48	-3.69

4. CONCLUSION

Dieng geothermal fluid is meteoric origin that experienced intense water - rock interaction, as can be seen from its gas, ^{2}H and ^{18}O isotope compositions. However, isotope data also indicate that there is magmatic contribution to the geothermal fluids.

Reservoir temperatures vary between production wells as inferred by gas geothermometer, where the lowest temperature 240^{o}C in HCE-7B and the highest 333^{o}C in HCE-28A. Some parts of the reservoir, such as HCE-7B, HCE-28B and HCE-31 had experienced boiling process in which the steam separated from up flowing fluids (vapor loss).

Further monitoring is needed not only or the gas but also for the chemical composition of the fluids. Result from this monitoring will be helpful in order to manage this field toward sustainable utilization.

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