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Preliminary characterization of thermal waters for direct-use application in Indonesia: Case study Dieng

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ABSTRACT

The amount of geothermal energy utilization of 1924.5 MW in Indonesia is still low compared to its 17,000 MW reserves. The development of the geothermal direct-use application for agriculture, farming, and space heating can be a catalyst to accelerate geothermal energy growth. The exploitation of manifestation water to be used as a working fluid for direct-use application can cut the excessive drilling expenditure. This study evaluates the geochemical properties of hot waters from geothermal manifestations in the Dieng region, Central Java, Indonesia, to be utilized for agriculture, aquaculture, and space heating. Published chemistry data of seven hot water samples in the region is analyzed based on solubility calculations and equilibrium modeling using PHREEQC to select the most suitable hot water type and assess scaling potential. The results of solubility calculation show: i) undersaturation of sulfate minerals (anhydrite and gypsum) in all samples, ii) oversaturation of carbonate minerals (aragonite, calcite, dolomite, and magnesite) in most of the samples, and iii) varying saturation level of silica minerals (chalcedony, amorphous silica, and quartz). Equilibrium modeling shows that the pipeline pressure has a negligible effect on the saturation index value of possible scaling minerals, further emphasizing the possibility of carbonate and silica scaling to form in some of the waters. The risk of scaling formation may be reduced by mixing thermal water with fresh water by considering heat loss potential.

1. INTRODUCTION

Indonesia has a total geothermal energy reserve of 17,000 MW, but only 2047 MW of these reserves is exploited for electricity production. As much as 312 geothermal fields have been identified across (Darma et al., 2020). Besides the significant issues that restrict the sector's development (economic viability, location of the project in the conservation forest, bureaucracy issues), social acceptance from local people also contributes to this delay. Previous studies suggest that utilizing and creating geothermal direct use facilities at the early phase of exploration may positively impact gaining acceptance from the local community. This approach is especially considered promising given that geothermal direct use application in Indonesia is underutilized compared to the geothermal potential (Adityatama et al., 2019)

Although Indonesia is amongst the leading producers of geothermal power generation, the country has a low recorded volume of direct-use annual capacity (11.8 GWh/yr based on Lund et al., 2010). In this respect, other countries with similar hydrothermal resources, such as the United States, Turkey, Iceland, and New Zealand, have been utilizing direct-use applications extensively. It is suggested that climatic conditions of non-tropical countries allow greater use of ground-source heat pump (GSHP) systems and the development of district heating systems. The underdevelopment of space heating is due to the country's geographic location in the tropic, in which weather tends to be the same all year long. However, the geothermal field location, which is mostly in the relatively colder mountainous region, suggests that the potential to develop space heating in these areas is not absent. Nonetheless, the vast agriculture, aquaculture, and aquaculture commodities produced in the vicinity of Indonesian geothermal areas, as well as the considerable interest of people for bathing, swimming, and therapeutic use using hot geothermal water, the potential of direct use utilization is still promising (Taqwim et al., 2015). The development of geothermal direct-use applications for agriculture, aquaculture, and balneology can be a catalyst to accelerate geothermal energy growth.

An example of direct use application from an existing powerplant is the mushroom cultivation in Kamojang. Steam from geothermal energy is extracted to substitute the use of LPG gas during the mushroom sterilization process. The application is especially advantageous in faster heating time (Fadli et al., 2015). Another example is the palm sugar processing facility in Lahendong geothermal field, which utilizes flashed steam from the separated hot water (brine) from a nearby powerplant. Pilot plants of geothermal energy direct use for coconut meat (copra) and cocoa dryings in Way Ratai Geothermal Field and catfish aquaculture has also been developed in Lampung Province. (Surana et al., 2010). Given the possibility of developing space heating facilities and the potential of direct use application for agriculture and aquaculture, direct geothermal use needs to be implemented in other Indonesian geothermal regions. One of the potential regions is the Dieng geothermal field located in Central Java at around 2000 m elevation. The annual temperature of the region is 14°C, with the coldest recorded temperature reaching -9°C. The region is also covered in productive agricultural land with various commodities.

Since geothermal project generally faces expensive investment issues, this study suggests that thermal manifestation with sufficient flow rate can be exploited to minimize cost. A preliminary study to assess these geothermal waters' suitability to be used for such application is required in that respect. This study evaluates the geochemical properties of hot waters from geothermal manifestations in the Dieng region, Central Java, Indonesia, to be utilized for agriculture (food drying, greenhouse heating), aquaculture, and space heating. Published chemistry data of nine hot water samples in the region is analyzed based on speciation-solubility calculations and pipeline equilibrium modeling using PHREEQC to select the most suitable hot water type and assess scaling potential, respectively.

2. GEOLOGY

Dieng geothermal field is located inside the volcanic highlands of the Dieng Plateau in Central Java at elevations of over 2000 meters. Dieng geothermal field has been generating electricity since 2002 with a capacity of 60 MW. The Dieng field's geology comprises Tertiary sediments overlain by several volcanic sequences (Figure 1). Rambatan Formation containing shale, marl, and calcareous sandstone formed during Early-Middle Miocene is the oldest unit in the area (Condon et al., 1996). This unit is unconformably overlain by Tapak Formation consisting of volcanic breccia and tuffaceous sandstone formed during middle Pliocene and Kalibiuk Formation consisting of marl and claystone respectively. These units are intruded by dioritic rock intrusion, which appears in the southwestern part of the area (Gaffar, 2017) (Figure 1).

Ligung formation consisting of andesitic volcanic breccia, hornblende andesitic lava, and tuff formed during Early Pleistocene is deposited unconformably above Tertiary units (Condon et al., 1996). Jembangan volcanics consisting of andesitic lava developed from the Early to Late Pleistocene cover large areas in the northern part of the field (Figure 1). Kaligetas Formation containing volcanic breccia, lava flows, tuff, tuffaceous sandstone, and claystone formed in Middle Pleistocene is exposed in the northeastern. Alluvial and lake deposit consisting of sand, silts, muds, and clay from the Early Holocene overlies these volcanic units.

Dieng volcanic complex composed of andesitic-lava and andesite-quartz developed during Early to Middle Holocene is deposited above alluvial and lake deposit. The volcanic complex is divided into two episodes: 1) Old Dieng (Prahu volcano, Pagerkandang caldera and Pangonan-Merdada caldera) and 2) Young Dieng (Bisma, Pakuwaja, Sikidang, Seroja, and Sikunir volcano) (Gaffar, 2017) (Figure 1). This unit is overlain with the recent volcanism of Sindoro volcano (Condon et al., 1996). Dieng geothermal system is associated with Pagerkendang and Pangonan-Merdada caldera from the Old Dieng volcanic complex (Harijoko et al., 2016). The studied area's regional structure has a caldera form with local fault trending southeast – southwest (Ramadhan et al., 2013).

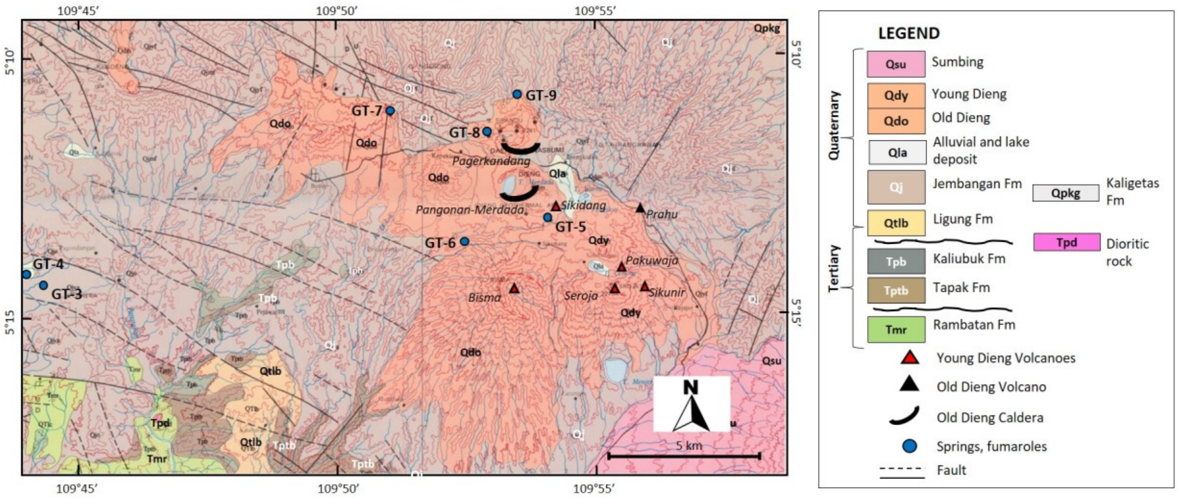

Figure 1: Geologic map of the study area from Condon et al. (1996) showing major volcanoes and thermal waters' location.

3. THERMAL MANIFESTATION

Geothermal manifestations in the Dieng field are found as hot springs and fumaroles in the following areas: Tempuran-Wanayasa (GT-3), Kaliputih-Wanayasa (GT-4), Kawah Sikidang-Batur (GT-5), Pulosari-Batur (GT-6), Kawah Candra Dimuka (GT-7), Kawah Sileri (GT-8) and Bitingan-Batur (GT-9). These samples' chemical composition is taken from a previous study by Ansori and Wardhani (2015). Tempuran-Wanayasa, Kaliputih-Wanayasa, and Pulosari-Batur are classified as alkali-chloride (Na+K-Cl) water. Sikidang-Batur and Kawah Candradimuka water are classified as calcium-sulfate (Ca-SO_4). Kawah Sileri and Bitingan-Batur waters are of alkali-bicarbonate (Na+K-HCO_3) type. In terms of pH, these waters are generally neutral except GT-5. The temperature of these thermal water ranges from 39.5 to 87.2°C, which are suitable for agriculture (Abdullah et al., 2010), aquaculture (Surana et al., 2010), and space heating (Sabah and Eyup, 2002). These thermal waters' hydrogeochemical facies are plotted in the Schoeller diagram (Figure 2) and piper plot (Figure 3). The highest flowrate is recorded in GT-9 (Ansori and Wardhani, 2015).

Table 1. Water chemistry of Dieng water (Flowrate in kg/s, EC in umhos/cm, concentration in mg/L) (Ansori and Wardhani, 2015)

Sample	pH	T (°C)	Flow rate	EC	Si	B	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Li^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	TDS
GT-3	7.03	39.5	50.18	3040	137.17	21.11	152.11	120.95	384.18	40.71	1.88	639.34	0	982.08	1950
GT-4	9.65	43.4	2.29	3050	165.43	21.36	189.74	148.25	352.92	41.77	1.54	538.46	0	1288.9	2138
GT-5	2.43	87.2	0	2260	226.16	0.02	68.13	11.33	18.58	10.08	0.01	2.64	996.12	0	2060
GT-6	6.03	57.4	1.57	1580	229.45	9.04	142.17	38.78	95.79	64.86	0.04	426.01	75.08	153.76	1812
GT-7	7.03	84	0	2880	37.61	1.78	26.38	11.15	6.18	3.01	0	4.34	895.42	60.66	1294
GT-8	7.04	59.6	37.46	1041	159.14	7.55	85.27	22.72	86.36	25.92	0.02	26.49	276.53	298.79	884
GT-9	7.68	64.7	115.23	706	189.18	3.17	45.4	15.49	87.45	35.04	0.04	10.98	73.82	361.45	722

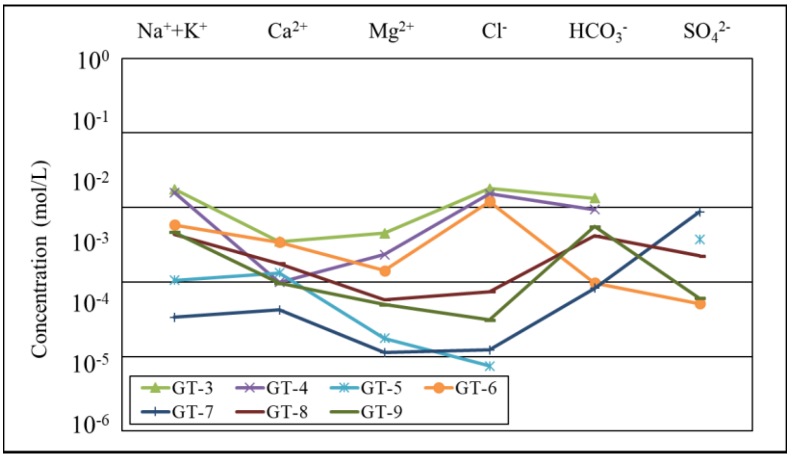

Figure 2: Schoeller diagram of Dieng thermal waters.

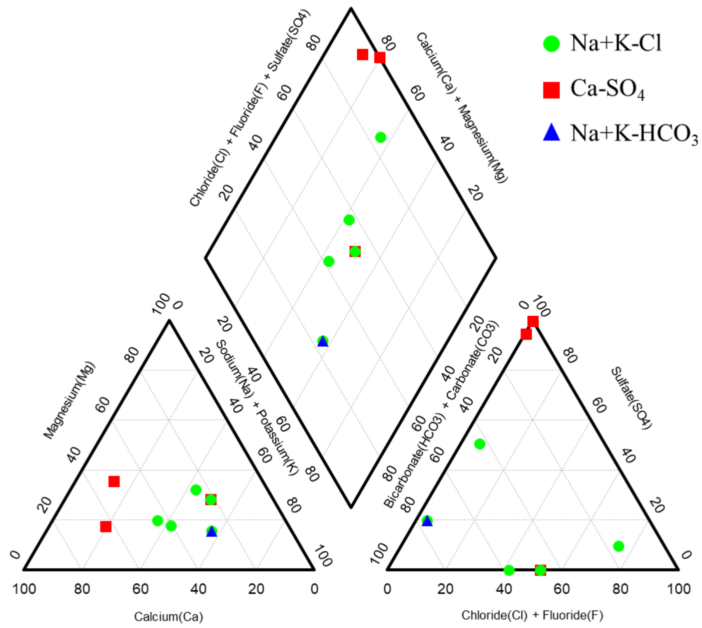

Figure 3: Piper diagram of the water compositions of Dieng thermal waters.

4. GEOCHEMICAL CALCULATION

One way to cut the expensive investment of exploiting geothermal energy is by directly extracting heat from the existing thermal manifestation. However, these manifestations require sufficient heat and flow rate and suitable chemical composition for it to be extracted. The example of a mushroom processing facility in the Kamojang field reported that it uses geothermal brine with a temperature of 105°C and a steam flow rate of 78.5 kg/h (Suyanto et al.,2010). Another example from the same study utilizes a geothermal downhole heat exchanger to extract heat from a low flowrate geothermal resource. In terms of chemical composition, the dissolved species in these waters may pose scaling potential to the pipes. Therefore, a geochemical calculation is required to assess such an issue.

This study's geochemical calculation is done using the PHREEQC program using saturation index calculation and equilibrium modeling. PHREEQC is a freeware that performs a wide variety of aqueous geochemical calculations and is used to model reactions and geochemical processes (Parkhurst and Appelo, 2013). The extended llnl.dat thermodynamic database is used during simulation in this study better to predict the solubility of CO_2 in a higher-pressure environment. Two calculations are created: 1) speciation and solubility calculation of geothermal waters, 2) Equilibrium modeling of these waters at a pipeline condition.

4.1 Speciation and solubility calculation

In the first calculation, possible scaling minerals' solubility is predicted based on the saturation index (SI). This parameter is utilized to determine the water's saturation state to a particular mineral. The saturation index is calculated based on the following formula

$$SI = log\left(\frac{IAP}{Ksp}\right) \tag{1}$$

IAP and Ksp are the ion activity product of a mineral's dissolved ions (e.g., Ca^{2+} and CO_3^{2-} for calcite) and mineral's solubility product, respectively. Water is classified as equilibrium with a particular mineral when its saturation index value is zero (SI = 0). Oversaturation and undersaturation are defined by positive (SI > 0) and negative (SI < 0) values, respectively. The saturation index indicates whether the relative abundance of dissolved species induces the dissolution or precipitation process.

In this calculation, the saturation of several potential scaling minerals is simulated, which are: sulfates (anhydrite, gypsum), carbonates (aragonite, calcite, dolomite, magnesite), and silica (chalcedony, amorphous silica, and quartz). The solubility calculation shows that all of the samples are undersaturated with respect to sulfate minerals. Based on the water type, the following observation is reported: i) Alkali-chloride samples show oversaturation of carbonate minerals in sample GT-3 and GT-4 and undersaturation of these minerals in sample GT-6 while oversaturation of silica minerals is observed except for amorphous silica in GT-3 and GT-4, ii) Calcium-sulfate samples show undersaturation of carbonate and silica minerals except in sample GT-5 in which chalcedony and quartz are slightly oversaturated, ii) Alkali-bicarbonate samples show oversaturation in carbonate minerals except magnesite in sample GT-8 and oversaturation of silica minerals except amorphous silica. The saturation index of simulated minerals is listed in Table 2.

Table 2. Saturation index of potential scaling minerals simulated with the studied samples.

Sample	Water Type	Anhydrite	Gypsum	Aragonite	Calcite	Dolomite	Magnesite	Chalcedony	Amorphous Silica	Quartz
GT-3	Na+K-Cl	-	-	0.5555	0.7004	2.7871	0.5453	0.8675	-0.0583	1.1257
GT-4	Na+K-Cl	-	-	2.5463	2.6911	7.0369	2.8256	0.4924	-0.4122	0.7474
GT-5	Ca-SO_4	-0.6924	-1.0659	-	-	-	-	0.5251	-0.1936	0.7489
GT-6	Na+K-Cl	-1.5154	-1.636	-1.2538	-1.1093	-1.2666	-1.6058	0.8437	0.008	1.0878
GT-7	Ca-SO_4	-0.9355	-1.283	-0.9401	-0.7953	-0.7413	-1.2735	-0.2285	-0.9582	-0.0027
GT-8	Na+K-HCO_3	-1.0751	-1.2151	0.1635	0.308	1.4706	-0.2752	0.6561	-0.1697	0.8985
GT-9	Na+K-HCO_3	-1.7673	-1.9518	0.7786	0.9231	2.9071	0.5706	0.664	-0.1398	0.9027

4.2 Equilibrium modeling

Equilibrium modeling is performed by reacting water samples with the expected pressure applied inside the pipes used for direct use application. This modeling aims to understand brine chemistry changes under the pipeline pressure environment after achieving equilibrium. Given that some of the water samples are collected from non-flowing sources (GT-5 and GT-7), they are not included in equilibrium modeling. A pressure of 7 atm is assumed to be applied to these samples if transported to direct use facilities. The modeling is used to further assess the potential of scaling of the previously simulated minerals. The result from this modeling shows that the pressure applied inside the pipeline has a negligible to minor effect on the saturation index calculation (see Table 3).

Table 3. Change in the saturation index value of potential scaling minerals after pressure is applied.

Sample	Flowrate	Anhydrite	Gypsum	Aragonite	Calcite	Dolomite	Magnesite	Chalcedony	Amorphous Silica	Quartz
GT-3	50.18	-	-	minor rise	-	minor rise	minor rise	-	-	-
GT-4	2.29	-	-	-	-	-	-	minor drop	minor drop	minor drop
GT-6	1.57	-	minor rise	minor rise	minor rise	minor rise	minor rise	-	-	-
GT-8	37.46	-	minor rise	Minor rise	minor rise	minor rise	minor rise	-	-	-
GT-9	115.23	-	minor rise	-	-	-	-	-	-	-

5. DISCUSSION

In terms of pH and temperature, all samples are suitable for direct use application except for sample GT-5. In terms of flow rate, the sample with high flowrate (GT-3, GT-8, and GT-9) can be extensively utilized and transported to a distant place from the source. Sample GT-4 and GT-6 may be transported for a limited distance, while the heat from sample GT-7 source can be extracted using a downhole heat exchanger (Suyanto et al., 2010). In addition, result from the modeling result in the following recommendation of usage based on the solubility calculation and equilibrium modeling: a) the sample of Tempuran-Wanayasa (GT-3) and Kaliputih-Wanayasa (GT-4) has the potential for carbonates (most likely dolomite), chalcedony, and quartz scaling to form, b) Kawah Sikidang-Batur (GT-5) is not suitable for direct use application due to its low pH value, c) Carbonate scaling is unlikely in Pulosari-Batur (GT-6), but silica scaling may form d) Scaling formation is also unlikely in Kawah Candra Dimuka (GT-7), e) There is a potential for carbonate mineral scaling (except magnesite), chalcedony and quartz in Kawah Sileri (GT-8), and f) Carbonate and silica mineral scaling are possible in Bitingan-Batur (GT-9) except amorphous silica. The oversaturation of minerals in these waters may be compensated by mixing with freshwater with relatively low content in dissolved species. However, temperature loss due to this procedure must be considered for optimum thermal water usage.

6. CONCLUSION

Geochemical properties of hot waters from geothermal manifestations in Dieng region, Central Java, Indonesia is investigated to be utilized for agriculture purpose, aquaculture, and space heating. Published chemistry data of seven hot water samples in the region is analyzed using PHREEQC based on solubility calculations and equilibrium modeling. The results form solubility calculation shows: i) sulfate minerals (anhydrite and gypsum) are undersaturated in all samples suggesting no potential scaling, ii) all of the samples is oversaturation with respect to carbonate minerals (aragonite, calcite, dolomite, and magnesite) except sample GT-6 and GT-7, and iii) varying saturation level of silica minerals (chalcedony, amorphous silica, and quartz) in all samples. In terms of equilibrium modeling, the applied pipeline pressure that is simulated has a negligible effect on possible scaling minerals' saturation index value. This result further remarks about the possibility of carbonate and silica scaling to form in some of the waters. The risk of scaling formation may be reduced by mixing thermal water with fresh water by considering heat loss potential.

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