# Geothermal Energy Potential of Arjuno and Welirang Volcanoes Area, East Java, Indonesia

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**Abstract-** Indonesia is a country having a high geothermal energy potential. The geothermal energy in Java island, as a volcanic row island, has been explored and produced. One of the areas that have not been produced is volcanic area around Arjuno and Welirang volcanoes located in East Java. Geochemical survey has been performed to explore a more detailed objective in exploring the potential resource of geothermal energy of this area. Chemical and isotopic analyses show the maturity level of waters taken from water springs in the area. The immature water from the water springs is interpreted coming mostly from meteoric water which flows quite fast forming water springs around the area. Geophysical analysis has been included to derive a more physical characters of the Arjuno-Welirang geothermal system. The geothermal reservoir thermometer has been predicted to arrive 300 to 350 degrees C. Using available data and information, geohydrothermal of the area has been modeled. Further, the energy potential has been calculated to achieve about 200 MWe.

**Keywords-** Geothermal energy, geochemical survey, geochemical analysis, geophysical analysis, geohydrothermal model, reservoir potential.

## 1. Introduction

Concerning the growth of human population, the government of Indonesia has long developed the country, including increasing electric power generation. With the decrease of hydrocarbon reserve, geothermal is a potential resource of a relatively renewable energy resource. Geothermal electric generation has actually long been developed due to the fact about potential geothermal prospect in Indonesia islands as of the intensive volcanic activities. Kamojang area, West Java is the first geothermal field that has long been developed since 1970s. The following area that has been able to generate geothermal electric power are Salak, Darajat, Dieng, Lahendong, Ulubelu, and many others.

Indonesia has potential geothermal energy resource with respect to significant volcanic activities. According to research and development that has been performed, it is known that geothermal resource potential in Indonesia reach approximately 27,791 MWe [1].

Arjuno-Welirang volcanic area in East Java Province south of Mojokerto city has geothermal potential, shown by existence of hot water springs. Exploration activities have been conducted. Geochemical survey and data analysis has been combined with refered geophysical data to produce geothermal model of the area. Geothermal energy potential was predicted using Monte Carlo simulation. This paper provides analysis and evaluation of research performed in 2016 in the area. Further and more detail exploration analysis may be conducted to explore more detail the area as well as capacity of possible potential in the area.

## 2. Geological Overview

Exploration survey has been performed in the area in early April 2016, beginning with field recognissance of the Arjuno – Welirang (AW) geothermal area. Geological condition of the area must be firstly searched to expand the survey especially for geochemical and geophysical exploration of the area. Volcanological area is very specific of Arjuno – Welirang geothermal area. Figure 1 shows specific morphology of the AW volcanoes. Figure 2 and 3 provide geological map and cross section of the AW geothermal survey area.

Hot springs appear in the western part of Arjuno-Welirang volcanoes, named Cangar, Padusan and Coban, indicates the possible resource of geothermal energy underneath the area. Although the volcanic rocks are mostly of Quarter age, the existence of heat source from the hot igneous rock and magmatic source could be explored further to explore the geothermal potential of the area.

Since there is no palaentological evidence such as various fossils indicating the age of the rocks, volcanic activity products are now described based on volcano stratigraphy, a stratigraphic method based on radioactive age description. This method is also mostly fit to geothermal exploration to predict the age of volcanic rocks where a geothermal system is developed.

A geological Team of The Survey Center of Geological Directory (Pusat Survei Direktorat Geologi, PSDG, Bandung, 2010) reported their geological mapping work. Based on volcano stratigraphic method, a geological map of Arjuno-Welirang volcanoes and surrounding area including Anjasmara area is shown in Figure 2 and 3.

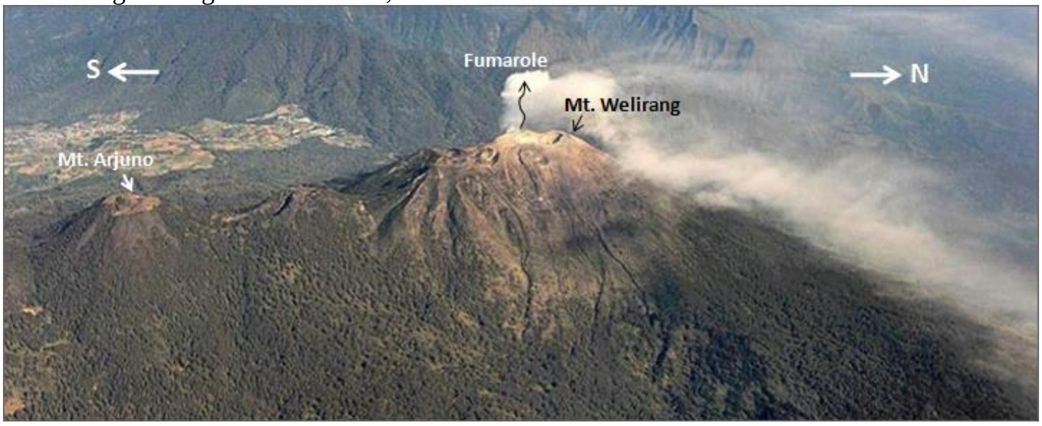


**Fig. 1.** Morphology of Arjuno-Welirang volcanic complex having geothermal surface manifestation signs in the area

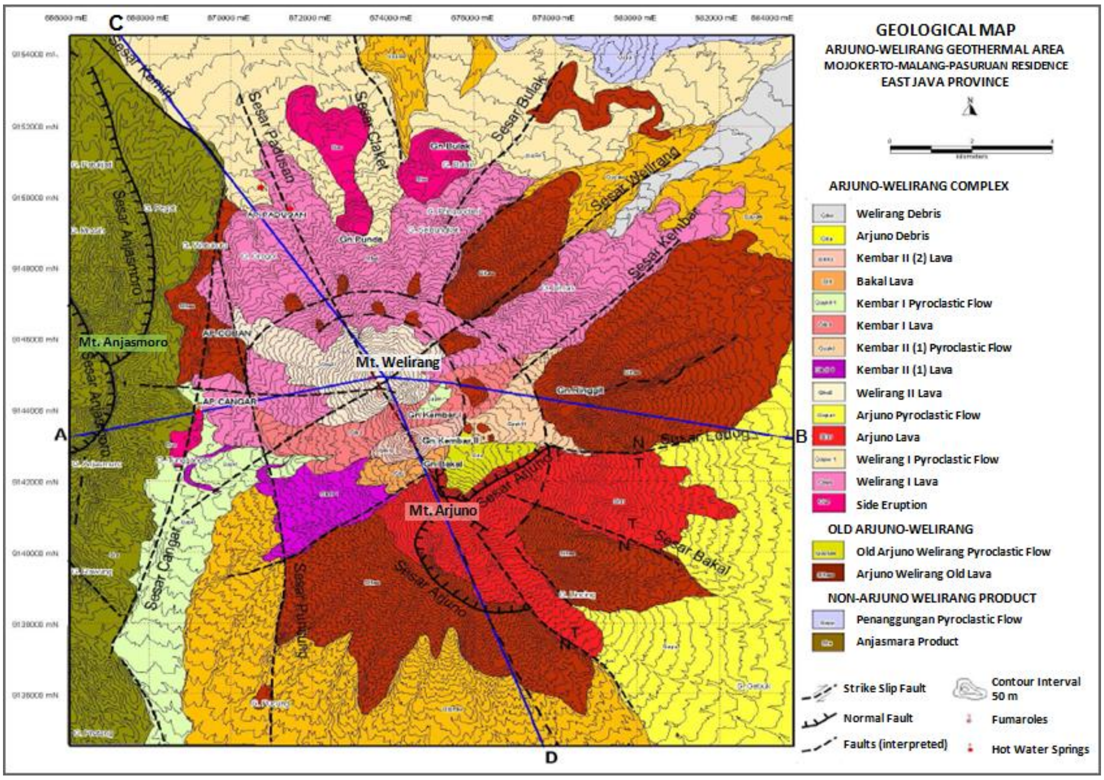


**Fig. 2.** Geological map of Arjuno-Welirang volcanoes area based on Volcano stratigraphy (Survey Center of Geological Directory [4])

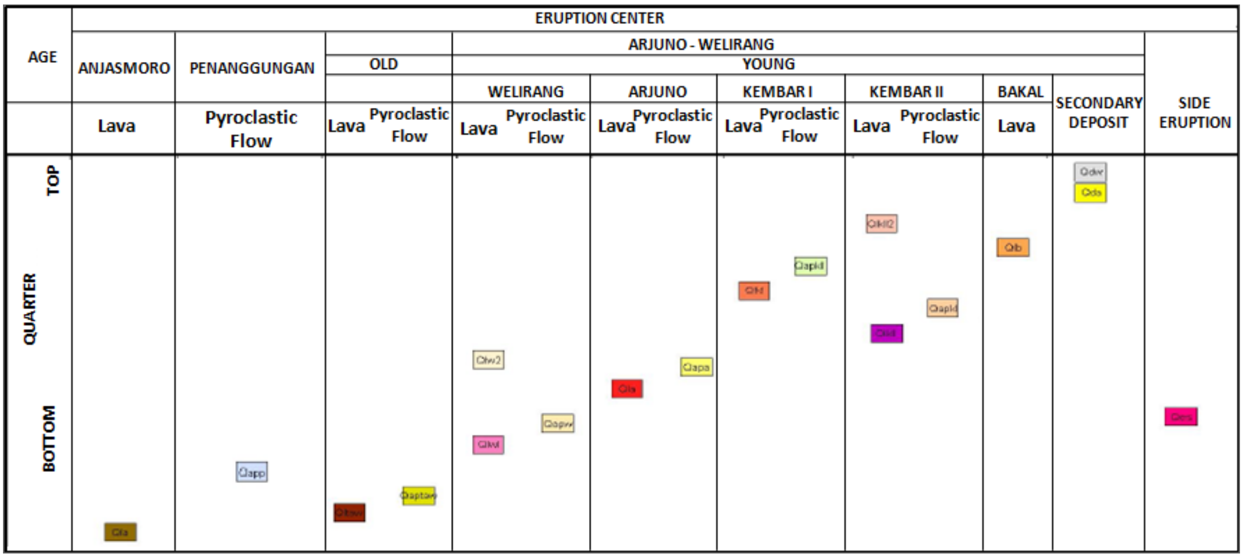


**Fig. 3.** Volcano Stratigraphy of Arjuno-Welirang volcanoes area (Survey Center of Geological Directory [4])

## 3. Geochemical Research

A geochemical survey has been performed by taking fluid samples from water springs of the Arjuno and Welirang (AW) and surrounding geothermal area, especially Cangar, Padusan and Coban area. From each location, two samples are taken for isotopic and chemical lab analysis. Table 1 shows the springs geographic position location data where the samples are taken from the AW geothermal area. Table 2 provides isotope analytical result ($\delta^{18}O$ and $\delta D$) from water samples taken in the field, while Table 3 presents result of general chemical lab analysis.

**Table 1.** Water samples from survey location around Arjuno-Welirang volcanoes.

| No | Water Source | Location (Village) | District & Regency | Geographic Positioning System & Topography | | | pH | Temp ($^0$C) | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | | | | LS (S) (..$^0$-..'-..") | BT (E) (..$^0$-..'-..") | Elevasion (m) | | | |
| 1 | Water spring on water fall | Cuban Canggu | Pacet, Mojokerto | 07-40-54,44 | 112-32-47,51 | 771 | 6 | 21 | Soth-West of G.Weliran |
| 2 | Hot spring | Cangar | Pacet, Mojokerto | 07-44-31,80 | 112-32-01,01 | 1568 | 7 | 55 | Warm water bath pool R.Soerjo Forest Park |
| 3 | Hot spring | Padusan | Pacet, Mojokerto | 07-41-14,59 | 112-32-59,57 | 887 | 6-7 | 55 | West of G.Welirang |
| | | | | | | | | | |

### Chemical Analysis Results:

**Table 2.** Outcome of $\delta^{18}O$ and $\delta D$ chemical lab analysis of water samples from Arjuno-Welirang and surrounding area.

| No. | Sample Code | $\delta^{18}O$ ($^0/_{00}$) | | | $\delta D$ ($^0/_{00}$) | | |
|---|---|---|---|---|---|---|---|
| 1 | WS around Coban Canggu | -7.26 | $\pm$ | 0.35 | -49.4 | $\pm$ | 1.8 |
| 2 | HWS Cangar 020416 | -9.30 | $\pm$ | 0.27 | -59.5 | $\pm$ | 1.1 |
| 3 | WS Padusan Pacet | -9.91 | $\pm$ | 0.47 | -69.2 | $\pm$ | 1.7 |

*) WS = Water Spring, HWS = Hot Water Spring

**Table 3.** Chemical Lab Analysis Results of Water Samples from the Arjuno-Welirang and surrounding area

| No. | Sample Code | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Na^+$ | $HCO_3^-$ | $Cl^-$ | $SO_4^-$ |
|---|---|---|---|---|---|---|---|---|
| | | (ppm) | (ppm) | (ppm) | (ppm) | (ppm) | (ppm) | (ppm |
| 1 | WS around Coban Canggu | 36.7 | 17.3 | 9.3 | 38.6 | 280.4 | 16.6 | 20.9 |
| 2 | HWS Cangar 020416 | 135.7 | 119.9 | 35.9 | 121.8 | 804.7 | 31.2 | 82.9 |
| 3 | WS Padusan Pacet | 214.2 | 148.3 | 60.0 | 258.5 | 5017.9 | 154.2 | 164.2 |

*) WS = Water Spring, HWS = Hot Water Spring

## 4. Geochemical Data Analysis

### *4.1. Geothermometer*

Early subsurface temperature of the geothermal system may be predicted by geothermometer methods developed by geothermometer experts i.e. using Na, K, Ca, and Mg (Fournier & Truesdell, 1973, Fournier, 1983, Truesdell, 1976, and Giggenbach, 1988) [5][6][7]. Table 4 provides the result of the above geothermometer analysis. From the calculation of three samples fluid chemical data there seems an extreme difference between geothermometer developed by Fournier & Truesdell [5] and Giggenbach [7] with the result of geothermometer by Fournier (1983) and Truesdell [6]. Two elements Na and K are relatively stable elements in a temperature changes. Therefore, geothermometer calculation of Fournier (1983) and Truesdell [6] are estimated to be more representing the subsurface condition around the Arjuno-Welirang (AW) geothermal field. With this estimation, the subsurface temperature of AW geothermal area could reach as high as 300 to 350$^0$C.

**Table 4.** Geothermometer of water samples from the Arjuno-Welirang and surrounding area

| No. | Sample Code | pH | Surface T | Geothermometer | | | |
|---|---|---|---|---|---|---|---|
| | | | ($^0$C) | Na-K-Ca Fournier & Truesdell (1973) | Na-K Fournier (1983) | Na-K Truesdell (1976) | K-Mg Giggenbach (1988) |
| 1 | WS around Coban Canggu | 6 | 21 | 162,01 | 306,07 | 307,15 | 34,18 |
| 2 | HWS Cangar 020416 | 7 | 55 | 170,91 | 331,25 | 343,76 | 30,66 |
| 3 | WS Padusan Pacet | 7,5 | 55 | 161,32 | 301,64 | 300,84 | 27,00 |
| | Average Temperature (degr C) | | | 164,75 | 312,99 | 317,25 | 30,61 |

### *4.2. Water Maturity*

According to the method developed by Giggenbach [7], plotting of Na, K, and Mg elements in triangular curve is performed with a result shown in Figure 4a. Geochemical survey and laboratory analysis performed by Integrated Survey Team of Geology and Geochemistry (ISTGG) [3] found result as shown in Figure 4b.

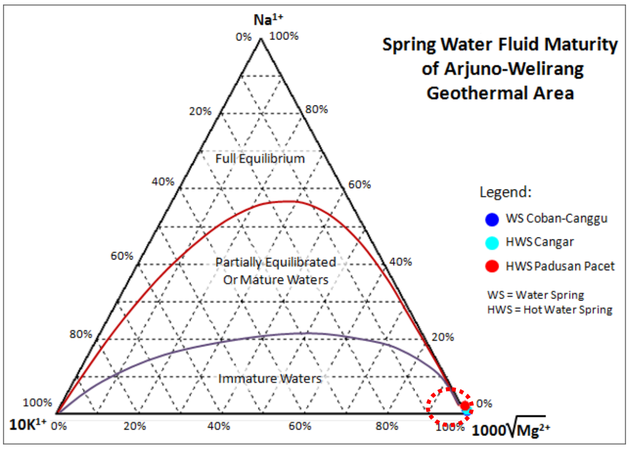


**Fig. 4a.** Na-K-Mg Triangular curve using chemical data of geothermal water spring fluids taken from Arjuno-Welirang volcanoes area.

From those figures it seems that the sample fluids are still immature fluids. This condition is estimated as a result of the possibility that the fluids are originated from meteoric fluids that has been permeated quickly in close distance for example from rain and fluvial water that permeated down earth and contact with hot igneous rock of Arjuno-Welirang volcanic intrusions. This contact of meteoric water and hot igneous rock results in rising the temperature of the meteoric water, that resulting flowing the fluid to the surface to become hot springs. This happens for example in hot springs of Cangar and Padusan Pacet area that located near the top of Welirang volcano as shown in Figure 2 and 3.

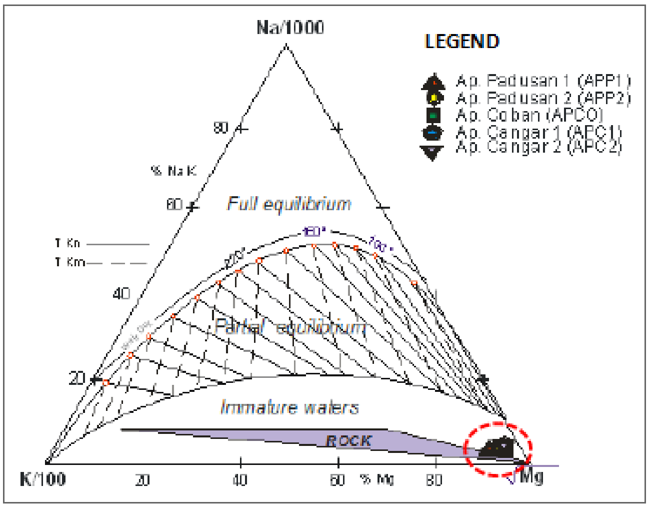


**Fig. 4b.** Na-K-Mg Triangular curve using data of survey and analysis by ISTGG [3]

### *4.3. Fluid Types*

Other chemical analysis has also been performed. Triangular curve of Cl, SO4, and HCO3 anions has been plotted based on a method developed by Arnorsson [8]. This method will provide the type of geothermal fluid source for which their samples have been taken for the analysis. Figure 5a presents the Triangular curve of Cl, SO4, and HCO3 anions. Geochemical survey and lab analysis performed by Integrated Survey Team of Geology and Geochemistry (ISTGG) [3] found result as shown in Figure 5b.

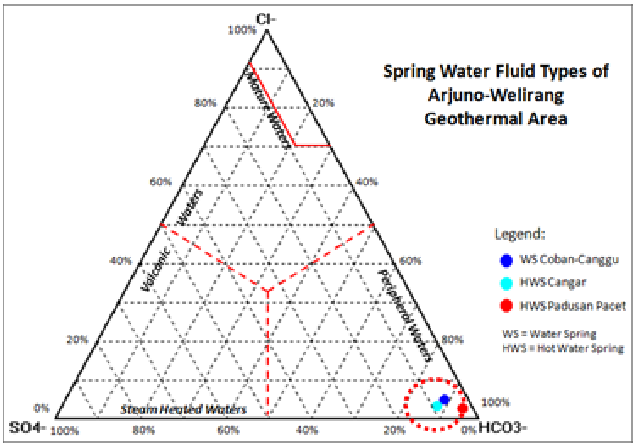


**Fig. 5a.** Cl, $SO_4$, and $HCO_3$ Triangular curve using chemical data of geothermal water spring fluids taken from Arjuno-Welirang volcanoes area.

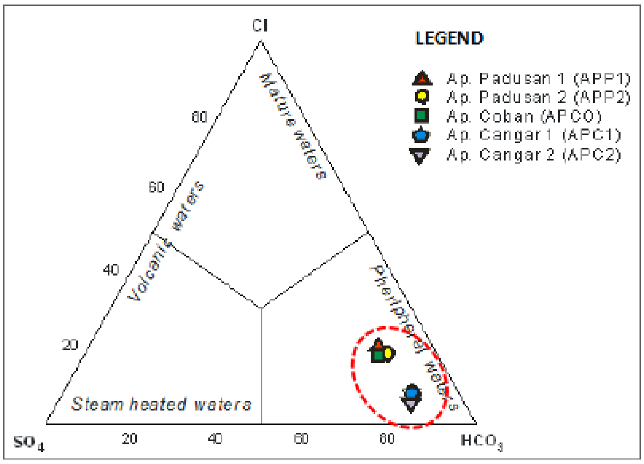


**Fig. 5b.** Cl, $SO_4$, and $HCO_3$ Triangular curve using chemical data of survey and analysis by ISTGG [3].

From Figure 5a and 5b it also can be seen the type of geothermal fluids which are included in Peripheral Waters, the type that in cross different with Mature Waters. Applying this analysis is also in accordance with Triangular curve of Na-K-Mg. It is interpreted that the fluids appears from the springs have not long been flown underground. It is flowing in short time due to relatively short time flow of rain water and high volume of fluvial water underground seepages around the Arjuno-Welirang volcanoes area.

### *4.4. Up-flow and Out-flow Geothermal Fluid Analysis*

Using the above available chemical data, analysis of possible geothermal fluids up-flow and out-flow has been performed. By knowing the decrease or increase of certain chemical concentrations are selected. Four analyses were conducted. Table 5 to 8 show possible fluid flow using chemical element concentration ratios. From this analysis it can be predicted where and how the possible underground geothermal fluid flow direction whether up-flow or out-flow around Arjuno-Welirang area.

**Table 5.** Geothermal fluid flow using concentration ratio of Na/K

| No. | Sample Code | $Na^+$ (ppm) | $K^+$ (ppm) | Na/K Ratio | Flow Direction |
|---|---|---|---|---|---|
| 2 | HWS Cangar | 121,8 | 35,9 | 3,39275766 | upflow |
| 1 | WS Coban-Canggu | 38,6 | 9,3 | 4,15053763 | |
| 3 | HWS Padusan Pacet | 258,5 | 60 | 4,30833333 | outflow |

**Table 6.** Geothermal fluid flow using concentration ratio of $SO_4/HCO_3$

| No. | Sample Code | $SO_4^-$ (ppm) | $HCO_3^-$ (ppm) | $SO_4/HCO_3$ Ratio | Flow Direction |
|---|---|---|---|---|---|
| 2 | HWS Cangar | 82,9 | 804,7 | 0,10301976 | upflow |
| 1 | WS Coban-Canggu | 20,9 | 280,4 | 0,07453638 | |
| 3 | HWS Padusan Pacet | 164,2 | 5017,9 | 0,03272285 | outflow |

**Table 7**. Geothermal fluid flow using concentration ratio of $Cl/SO_4$

| No. | Sample Code | Cl (ppm) | $SO_4^-$ (ppm) | $Cl/SO_4$ Ratio | Flow Direction |
|---|---|---|---|---|---|
| 3 | HWS Padusan Pacet | 154,2 | 164,2 | 0,93909866 | upflow |
| 1 | WS Coban-Canggu | 16,6 | 20,9 | 0,79425837 | |
| 2 | HWS Cangar | 31,2 | 82,9 | 0,37635706 | outflow |

**Table 8.** Geothermal fluid flow using concentration ratio of Na/Ca

| No. | Sample Code | Na (ppm) | Ca (ppm) | Na/Ca Ratio | Flow Direction |
|---|---|---|---|---|---|
| 2 | HWS Cangar | 121,8 | 135,7 | 0,89756817 | upflow |
| 1 | WS Coban-Canggu | 38,6 | 36,7 | 1,05177112 | |
| 3 | HWS Padusan Pacet | 258,5 | 214,2 | 1,20681606 | outflow |

### *4.5. Isotopic Analysis*

The water fluid types can be analyzed using isotopic characteristics. Isotopic laboratory analysis has also been performed to the spring water samples taken in Arjuno-Welirang area. Figure 6 shows plot of Deuterium and Oxygen isotopes using data from Table 2.

From the isotopic curve in Figure 6 it is clearly seen the trend of local spring water characteristics of Arjuno-Welirang (AW) area. The trend of geothermal water line of AW area almost fit to Meteoric Water Line trend, but still far from Magmatic (Andesitic) water of the area. From this feature it can be interpreted that there was not much mixing of meteoric water and magmatic water. It is even predicted that the spring water is dominated by meteoric water coming from rain as well as fluvial water from surrounding the AW area. This indicates that the local AW geothermal water is much coming from meteoric water that precipitates underground from surface, touching hot igneous rocks, then flows up to the surface forming hot springs near Welirang volcano.

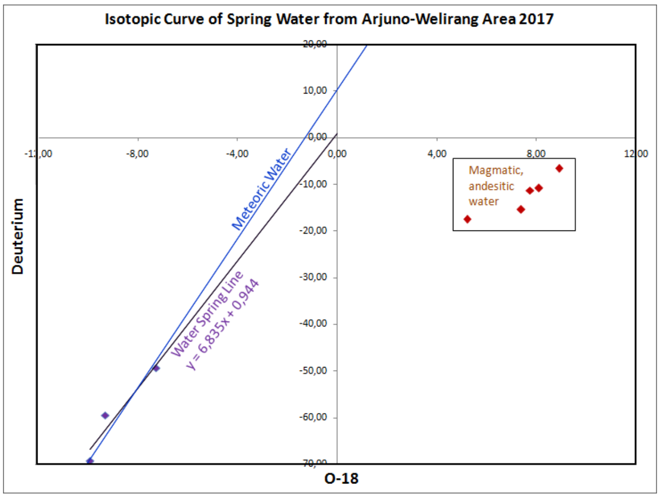


**Fig. 6.** Isotopic curve of Deuterium and Oxygen using data from Arjuno-Welirang volcanoes area (Table 2).

## 5. Geophysical Data Analysis

To overwide the physical characters of Arjuno-Welirang geothermal system, several experts have conducted geophysical survey and research in the Arjuno-Welirang area. Sunaryo [11] had performed gravity as well as magnetic survey and data analysis. Figure 7 shows Horizontal gradients residual total magnetic anomaly map of Arjuno-Welirang geothermal area which indicates heat source possible area

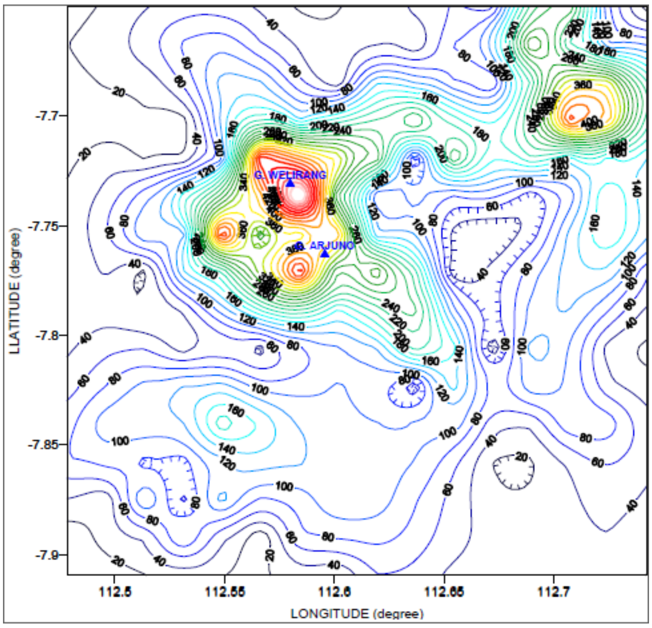


**Fig. 7**. Horizontal gradients residual total magnetic anomaly in Arjuno-Welirang geothermal area [11]

Daud et al. [12] had conducted Magneto Telluric geophysical survey and data analysis. Using the existing available geophysical data and analysis results, Wardana et al [13] performed available data simulation. Based on a conceptual model, a natural state numerical model is generated using available simulator.

According to Daud et al. [12] Arjuno-Welirang reservoir geological structure is shown in Figure 8a. Meanwhile, Wardana et al. [13] produced a model as shown in Figure 8b.

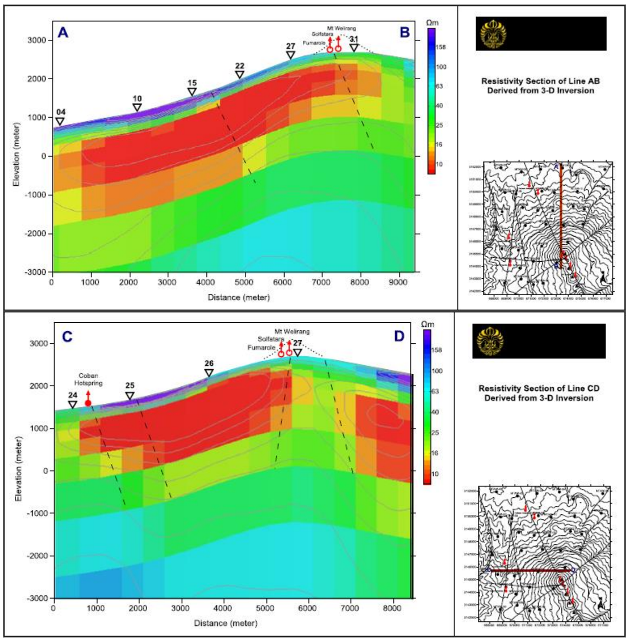


**Fig. 8a.** Resistivity structure of subsurface and reservoir profile using MT geophysical data analysis (Daud et al. [12]) (Notes: The crosslines A-B and C-D are shown in the index maps of these figures).

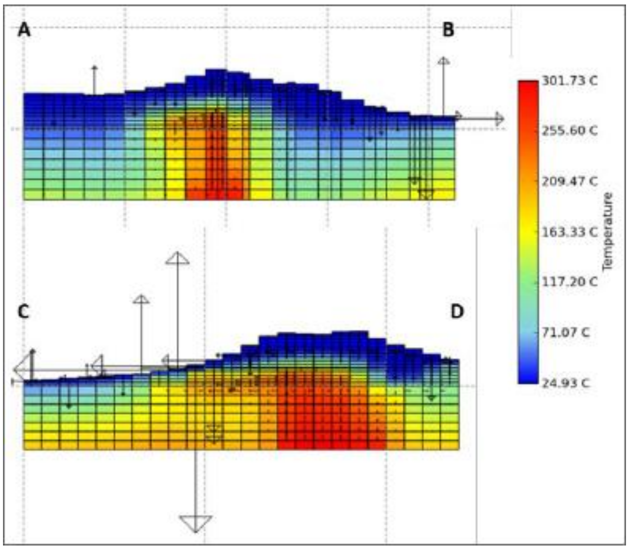


**Fig. 8b.** Temperature profile of A-W geothermal model using natural reservoir simulation, showing extending to a depth of 3500 meters below sea level (Wardana et al. [13]) (Notes: The crosslines A-B and C-D are shown in Figure 2).

## 6. Geohydrothermal Modeling

Using the above geological as well as geochemical and geophysical data, information and evaluation, it can be analyzed the possible geohydrothermal model of the Arjuno-

Welirang area. As described in the geological data and analysis, the rocks dominantly exist in the AW area are Quarter-age volcanic and igneous rocks. Figure 2 and 3 present the geological condition in the area.

Using geographic positioning system data taken while survey in the field is used to configure the location of geological position of fluid samples taken from the Arjuno-Welirang mountain. Figure 9 shows where relatively hot and cold surface temperature springs are found. The surface temperature may also be used as data to interpret the up-flow and out-flow zones of the geothermal system developed in the area as shown in Figure 10.

Because of the young age and lithification level, the geothermal area rocks are composed of igneous and volcanic rocks. Figure 10 provides the illustration of cross section between Mount Arjuno to Mount Welirang and up to the surrounding area. The figure also presents rocks types below the area as depicted in Figure 2. The igneous rocks could be formed by intrusion and extrusion of subsurface magma in the AW mounts, forming lava flow as well as intrusive rocks below the area. While the extrusive rocks were generated by explosion of the volcano's magma, forming fragmented grains to product breccia, sand, and tuff deposits. As the volcanism activity decline, the deposits become porous and permeable young volcanic extrusive rocks.

As shown in Figure 10, the compact and chrystalline igneous rocks may be function as heat conductor from subsurface magma and hot igneous rocks source, while the porous and permeable volcanic rocks transform the water from rain fall and fluvial surface rivers that precipitates and flows down from surface. This seepaged water will flow to reach hot igneous rocks to become hot water. Further the heat will expand the water volume to become less heavy water and easily flow back up to the surface. When it reaches the earth surface, it forms hot springs such as the ones present in Padusan and Cangar hot springs in western area of Welirang Mount.

Triangular curve shown in Figure 4 provides the maturity of the most water taken from the springs around the Arjuno-Welirang area. The relatively short distance and the time of water flow from surface down to the heat source and back up flows to the surface will product hot water that is relatively young age to become immature water. Meanwhile Figure 5 shows the fluid types of most water from the springs around the AW area, which belongs to peripheral water type.

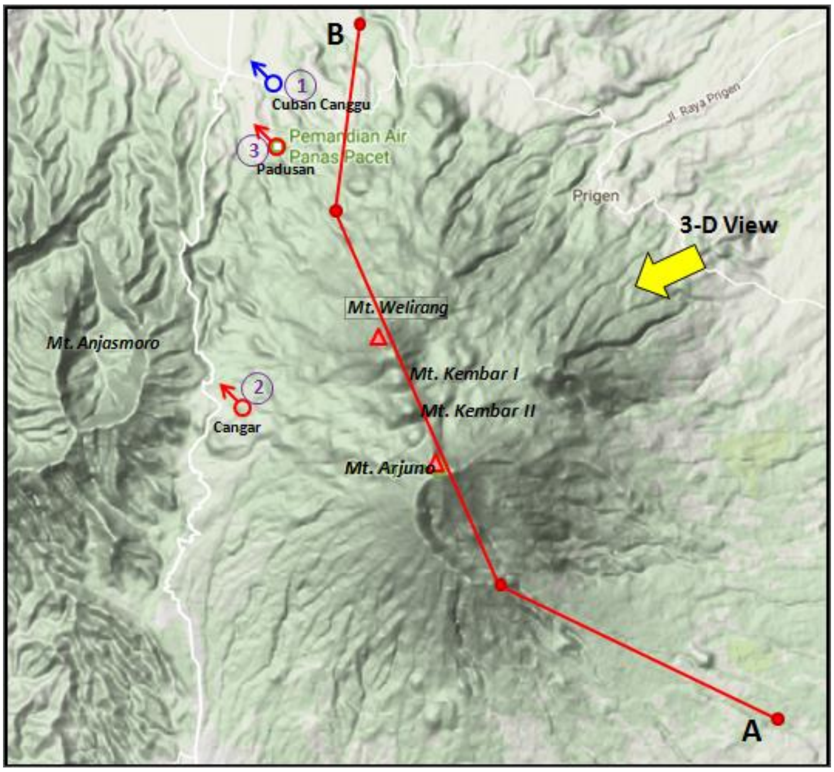


**Fig. 9.** Location map of geothermal water samples taken from water springs in the Arjuno-Welirang geothermal area, East Java, Indonesia

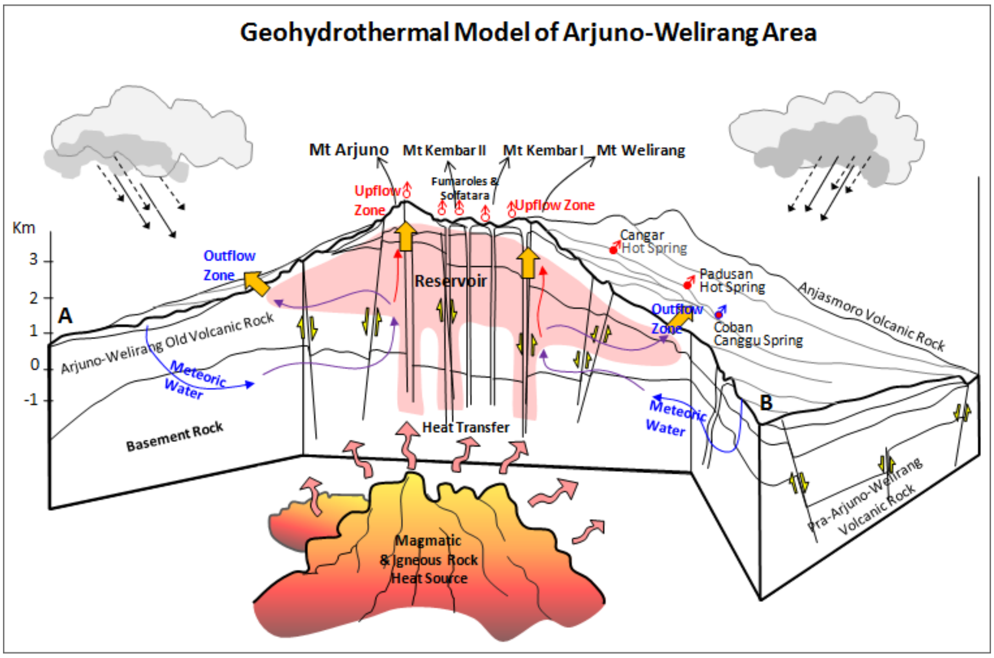


**Fig. 10.** A-B cross section of the Arjuno-Welirang geothermal area showing geohydrothermal model of water springs around area.

## 7. Geothermal Energy Potential

Geothermal energy (heat) potential may be predicted quantitatively using various method that have been developed by experts. Sanyal et al. [9] has developed a heat energy transport particularly through conductive flow in the rock to be used as basic equation for computing heat reserve in a geothermal reservoir. Sarmiento et al. [10] presented another method with special application for geothermal heat flow. Sarmiento's method presents two equations for steam and water dominated reservoir fluids.

A simple method has been developed by a Geothermal Standardization Team in The Survey Center of Geological Directory (ISGD) (Pusat Survei Direktorat Geologi, PSDG, Bandung, [2]. The equation used and developed by the team is:

$$Q = 0{,}11585 \times h \times A \times (T_{ag} - T_{cut-off}) \qquad (1)$$

where:
Q = Energy Potency (MWe)
A = Reservoir Heat Distribution (km$^2$)
h = Reservoir Thickness (km)
$T_{ag}$ = Reservoir Temperature (°C)
$T_{cut-off}$= Cut-off Temperature (°C)

The above formula is a applied based on volumetric unit (i.e. h x A). By computing the reservoir volume, it is then multiplied by temperature difference between initial reservoir temperature and cut-off or rejection temperature (i.e. final reservoir temperature capable to produce steam for supplying the turbine of the geothermal electric power generator). The reservoir heat distribution area has been identified by a geophysical research [12]. The reservoir heat distribution area (A) was computed to find 43.25 km$^2$ as shown in Figure 11. While the reservoir thickness (h) is calculated to find approximately 600 m. According to geothermometer prediction described in part 4.1, initial reservoir temperature ($T_{ag}$) is 320$^0$C and using cut-off temperature ($T_{cut-off}$) of 180$^0$C, reservoir energy potential (Q) could be computed using Equation (1). Using data and information regarding the Arjuno-Welirang geothermal area and by applying Monte Carlo Simulation, the geothermal (heat) potential is calculated to reach approximately 200 MWe.


**Fig. 11.** Reservoir area of Arjuno-Welirang geothermal potential.

## 8. Hybrid Renewable Energy System

Geothermal energy reserve in an area can be varied, not only the energy content but also the continuity and stability during the utilization. Therefore, efficiency to utilize the potential is possible to join the hybrid system. As shown by

Marchenko & Solomin [15] that their study demonstrates a considerable economic effect of the renewable energy sources for many considered variants. However, the most preferable option is the combined use of different renewable energy sources: wind turbines, photovoltaics and a biomass gasification power plant [15]. With the result of their study, it is recommended the geothermal energy reserve as renewable energy resource to be combined in hybrid system. Figure 12 shows the scheme of the hybrid system. In the small generator capacity, it can use super capacitor (SC). It is an energy storage technology that is rapidly developing, and being implemented in various industrial applications. Several electric rail transportation systems currently use super capacitors for voltage enhancement, and improved recuperation of regenerative braking energy (Khodaparastan et al.) [16].

A study and analysis performed by Alvarez et al [19] found that microgrid hybrid in Colombian community of Unguía could be optimized although using diesel generator. The renewable energy resources play important roles in the microgrid hybrid system [19]. With this recovery, geothermal energy resource potential may play important role in the system. Figure 13. show possible geothermal energy source play in the microgrid hybrid system.

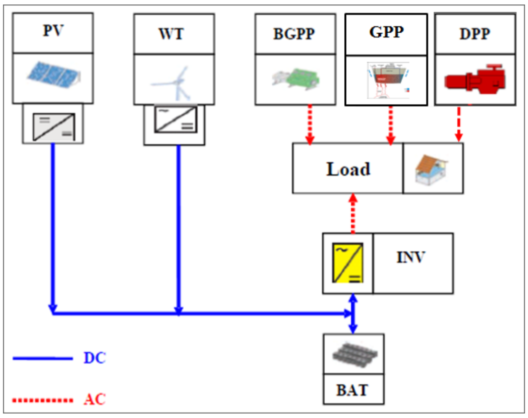


**Fig. 12.** Energy flows in the power supply system (PV – photovoltaic modules, WT – wind turbine, BGPP – biomass gasification power plant, GPP – geothermal power plant, DPP – diesel power plant, INV – inverter, BAT – battery) (Modified from Marchenko & Solomin) [15]

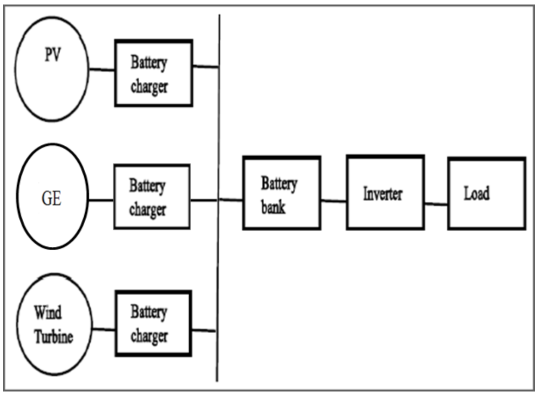


**Fig. 13.** Schematic diagram of a typical hybrid RE system including Geothermal Energy Power [16]

Paragond et al. [18] presents design and simulation of PV (Photovoltaic) and wind hybrid Energy system (WECS) in isolated mode of operation. By the charactristics of geothermal energy source, it is possible to include geotherrmal electric into this isolated hybrid system.The output voltage from multi sources are given to DC link by using to DC-DC converters in order to maintain constant DC link voltage. Single phase Inverter with unipolar voltage switching is used. The Total Harmonic Distortion (THD) of load voltage is analyzed. Quite satisfying results opens the possiblity to apply the outputs involving geothermal electric source [18].

## 9. Hybrid RE System Economy & Management

In order to handle Hybrid RE system, it is supposed to manage efficiently. Economic analysis is related closely in the management. Mas'ud [17] found that techno-economic analysis of a hybrid renewable system conducted to analyze a hybrid project for critical loads in Nigeria which is used to supply a district hospital was accomplished [17]. With this recovery, it is possible that geothermal energy as a renewable energy be combined in the hybrid RE system conducted in the analysis. Figure 14 shows the schematic typical hybrid RE system being analyzed. Turker et al. [21] found management and economic system called Energy Management Strategy (EMS) applicable to electric power generation hybrid system quite efficiently. To improve the hybrid integration, it is recommended to control the energy production in order to increase economic viability, to decrease the impacts on the grids and potentially that can be traded on electricity markets like the conventional power plants/producers [21].

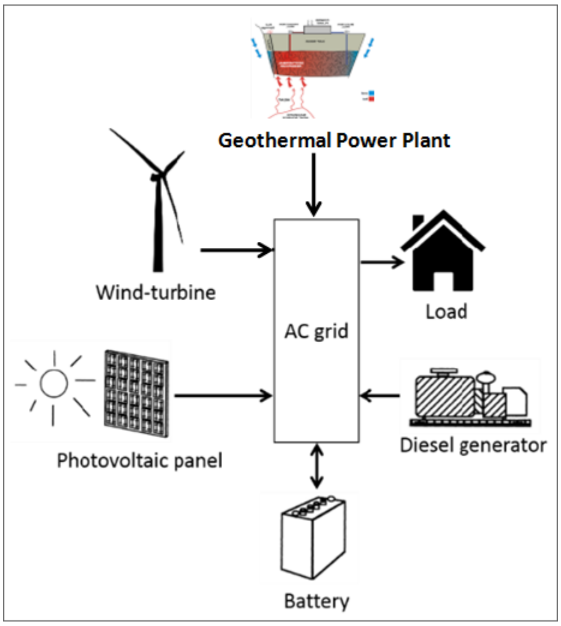


**Fig. 14**. Scheme of a hybrid microgrid [17]

The rapid development of renewable energy systems (RES), for example geothermal energy, photovoltaic (PV) energy, and wind energy, poses increasing requirements for highpower, low-loss, fast-switching, and reliable semiconductor devices to improve system power capacity, efficiency, power density and reliability. He et al. [22] performed analysis of the performance benefits and application challenges of using Silicon Carbide (SiC) or Gallium Nitride (GaN) devices in both PV and wind energy conversion systems. They found the benefits of using such emerging devices were confirmed in simulation based on a 250 kW commercial-scale PV inverter and a 250 kW doubly fed induction generator wind turbine system [22].

Meanwhile Verdugo et al [20] performed study and analysis of electricity power generator control strategy. High voltage direct current (HVDC) transmission networks is one of the most interesting systems for the application of modular multilevel converters. Stability improvement of large interconnected systems is essential [20]. Verdugo et al [20] presents a control strategy to provide support to the grid against disturbance in a HVDC system implemented with a modular multilevel converter (MMC). The main idea behind this work is to replace the classical power controller by a new control strategy, which emulates the characteristics of a synchronous generator. The control proposed is known as Synchronous Power Control (SPC) and it is able to emulate inertia, damping and droop characteristics required by the grid.

## 10. Conclusions and Recommendation

Geothermal exploration survey has been performed in Arjuno-Welirang volcanic area, East Java. It can be concluded that,

1) Geothermal manifestation of hot water springs, rock alteration, and other typical geothermal manifestation can be found in the area. Samples from water springs in the area have been taken for geochemical analysis and evaluation.
2) Geochemical data analysis shows that the spring waters are dominantly immature, shows up from meteoric water that has been heated by hot conducted subsurface magma and igneous rock. It then flows up to the surface through porous and permeable volcanic rocks forming hot water springs.
3) Geophysical data analysis predicted the reservoir geometrical position and temperature profile. Geothermal fluid convective upflow and outflow and heat conductive possible directions can also be interpreted.
4) The subsurface water flow that are not heated has flown through porous and permeable volcanic rocks to form cold water springs far from heat source below Welirang-Arjuno volcanoes.
5) Using available data and information, the geothermal energy (heat) potential of Arjuno-Welirang area may reach approximately 200 MWe.
6) Geothermal energy potential in Welirang-Arjuno area can be included in a hybrid system with other new and renewable energy resources (PhotoVoltaic, Wind, etc), by technical operation, management and economy efficiently to provide effective outcome.

Further searches could be performed to evaluate and analyse the energy (heat) potential of the Arjuno-Welirang geothermal area.

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