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Geological and environmental implications of the utilisation of geothermal energy in the Lahendong working area, Indonesia

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Abstract: This study presents the characteristics of the Lahendong geothermal working area (GWA) in terms of the geological, geophysical, geochemical, and environmental implications. The investigated area is located in the Sulawesi North Arm, where the volcanic arc extends from Sangihe Island to Minahasa with two major strike-slip faults. NE–SW (northeast-southwest) trending faults control the thermal surface manifestation. The geothermal field is grouped into two hydrochemical systems: acid-sulphate-chloride (acid reservoir) and chloride (closer to neutral) types. The environmental implication analysis shows that the North Sulawesi province is experiencing water shortages due to excessive mining activities, inadequate wastewater management, and periods of drought. Although geothermal wastewater is being re-injected, the possibility of water contamination by hazardous materials from geothermal power plant activity is still evident. This study reviews the actual geothermal utilisation in the form of the 120 MWe power plant, the 500 kWe binary power plant, while the heat from geothermal energy is used for palm sugar production. Furthermore, the article also analyses the potential of the rational use of geothermal resources in this area. As a result of the high salinity and silica concentration of the brine, the geothermal wastewater should be treated before further utilisation and it potentially benefits both local communities and geothermal companies.

Keywords: geothermal system, geothermal direct utilisation, geothermal desalination, environmental impact

INTRODUCTION

The development of renewable energy sources to replace fossil fuels is a trend which is currently widely encouraged. Geothermal energy is considered to be the most promising sustainable and renewable source of energy, with high availability and its potential utilisation still largely untapped (Zhu et al. 2015, An et al. 2016, IRENA 2017). Moreover, compared to solar and wind energy, geothermal energy provides higher variability and an intermittence which can be exploited in every part of the world (IRENA 2017). It has been proven that geothermal resources are more than sufficient to meet the energy needs of human consumption. In addition, compared to fossil fuels, geothermal power generation brings a number of benefits, such as lower life-cycle greenhouse gas emissions; lower running costs; the capability to supply baseload electricity, flexibility and ancillary services to a system; and higher capacity factors (IRENA 2017, Nian & Cheng 2018). Consequently, the utilisation of geothermal energy will contribute to reducing global warming effects and public health risks. Besides the mentioned advantages of geothermal energy, drawbacks include being restricted to specific locations and potentially triggering earthquakes. Moreover, the main barrier to further geothermal development lies in the difficult task of securing funding for surface exploration and drilling operations.

It is widely known that Indonesia is located along the ring of fire of the Indo-Pacific region and hence is prone to various harmful seismic activities, such as earthquakes, volcanism, and other events triggered by the movement of tectonic plates (Pambudi 2017). However, such a location also means abundant geothermal resources spread through Sumatra, Java, Nusa Tenggara, Maluku, North Maluku, and Papua, amounting to 342 geothermal resource locations in total. The Geological Agency of the Ministry of Energy and Mineral Resources (Ministry of Mineral and Energy Resources 2015) estimates that there is 28,508 MWe of geothermal energy potential spread throughout Indonesia. In 2020, Indonesia produced 2.289 GWe of electricity from geothermal energy resources, thus becoming the second-largest country after the USA to utilise the energy potential for electricity production (Huttrer 2020). Moreover, geothermal energy can be used directly in space heating, greenhouses, agriculture, plantations, forestry, breeding, and desalination. However, this prospect has not been extensively studied as the annual direct use of geothermal energy in Indonesia is considered low (only 11.83 GWh/year) (Lund & Toth 2020). Other promising opportunities for geothermal power production are through the utilisation of geothermal waste heat in the form of brine or steam.

This study presents the essential parameters in assessing the rational use of geothermal resources. The first part focuses on analysing the geological, geophysical, and geochemical conditions of the Lahendong area. Moreover, the environmental implications of the geothermal working area are also analysed. Finally, the existing and potential utilisation of the geothermal resources in this area is presented.

STATE-OF-THE-ART OF THE LAHENDONG GWA, INDONESIA

In this section, the information about important aspect of geological, geophysical and geochemical studies in this geothermal field will be present. This information is necessary to address the potential utilisation of geothermal resources in this area.

Geological aspects and thermal surface manifestations of the Lahendong GWA

Lahendong is located at the Sulawesi North Arm as a part of the volcanic arc that stretches from Sangihe Island to the Minahasa coast. The North Sulawesi Trench formed due to the subduction of the Celebes Sea Plate to the south below the Sulawesi North Arm (Simandjuntak & Barber 1996). The volcanic arc is stretched from the Sangihe Island to the Minahasa region and was initially formed by the subduction of the Molucca Sea Plate to the west (Simandjuntak & Barber 1996). The Minahasa tectonic elements are shown in Figure 1. Vice Ganda & Sunaryo (1982) on Utami (2004) stated that the Lembeyan volcanic complex is the oldest volcano in Minahasa (Utami et al. 2004). The volcanic activity in Tondano resulted in the formation of Tondano, which is dominated by a rhyolite tuff. The formation of Post Tondano is the result of volcanic activity that are believed to have developed after the collapse of the calderas of Tondano. Most of the basalt, andesite lava and pyroclastics from small volcanic centres dominate this formation. Thereafter, the immediate vicinity of the shoe-shaped structures of the Tondano caldera and the Pangolombian horse were formed (Fig. 2). This volcanic activity in the Kasuan and Lengkoan volcanic centres was active during the Miocene, producing breccia, lava, and tuff andesitic to basaltic (Siahaan et al. 2005). The remnants of the caldera wall form hills eastwards from Tondano Lake.

A major volcanic eruption occurred during the Late Pliocene or the Early Pleistocene, spilling out several hundreds of cubic kilometers of tuff and ignimbrites, forming the large volcano-tectonic depression of Tondano (a part of which is now occupied by Lake Tondano) (Siahaan et al.

2005). The volcano-tectonic trends which is 20 km of long structure (NNE–SSW) and parallel to the Sangie Arc. A smaller eruption centre emerged within the depression of Tondano and is known as the Pangolombian depression in which the geothermal field of Lahendong emerges (Koestono et al. 2010). Lahendong is situated between Mt. Soputan and Mt. Riendengan and Mt. Lokon-Mahawu. Utami et al. (2004). A geological map of the Lahendong geothermal system is presented in which there are two major strike-slip faults in this geological system, and the out-turn stepped across the fault zones.

The Lahendong geothermal system is the only example of an arc–arc collision zone in the world (located in the Sangihe arc, Sulawesi North Arm) (Utami et al. 2015) and the tectonic activity in the area confirms the existence of such a zone. The age dates of rocks that were assumed to correlate with the system's reservoir rocks suggest that the system might have started its activity at 2.2–0.5 Ma. Thus, despite the fact that the absolute age of the Lahendong geothermal system has not been determined, the system emerged shortly after (or shortly before) Tondano's volcanic activity ceased (Hochstein & Sudarman 2008). The latest volcanic and tectonic activity in the enclosing zone influenced the geothermal system.

The main thermal manifestations are observed on the western and northern shores of the Linau Lake, Leilem, Lahendong, and Kasuratan, as shown in Figure 2. They all belong to the steam-heated type and are mainly controlled by the NE–SW trending faults – there is no pH-neutral discharge of water in the Lahendong region (Utami et al. 2004). The manifestations typically contain altered and steaming dirt, hot springs of acid sulphate, mud baths, mud pools (with or without mud volcanoes), and discharges of hydrogen sulphide gas (Utami 2011). Common minerals are kaolin, residual silica, sulphur, very fine-grained pyrite, aluminium salts, and iron oxide in the altered soil (Utami 2011). The most active thermal activity is in Linau, where some fumaroles occur at a temperature of 106°C. This is home to both the hottest steaming ground (T = 60–98°C at 45 cm depth) and the hottest acid sulphate springs (T = 80–90°C, pH = 2–4).

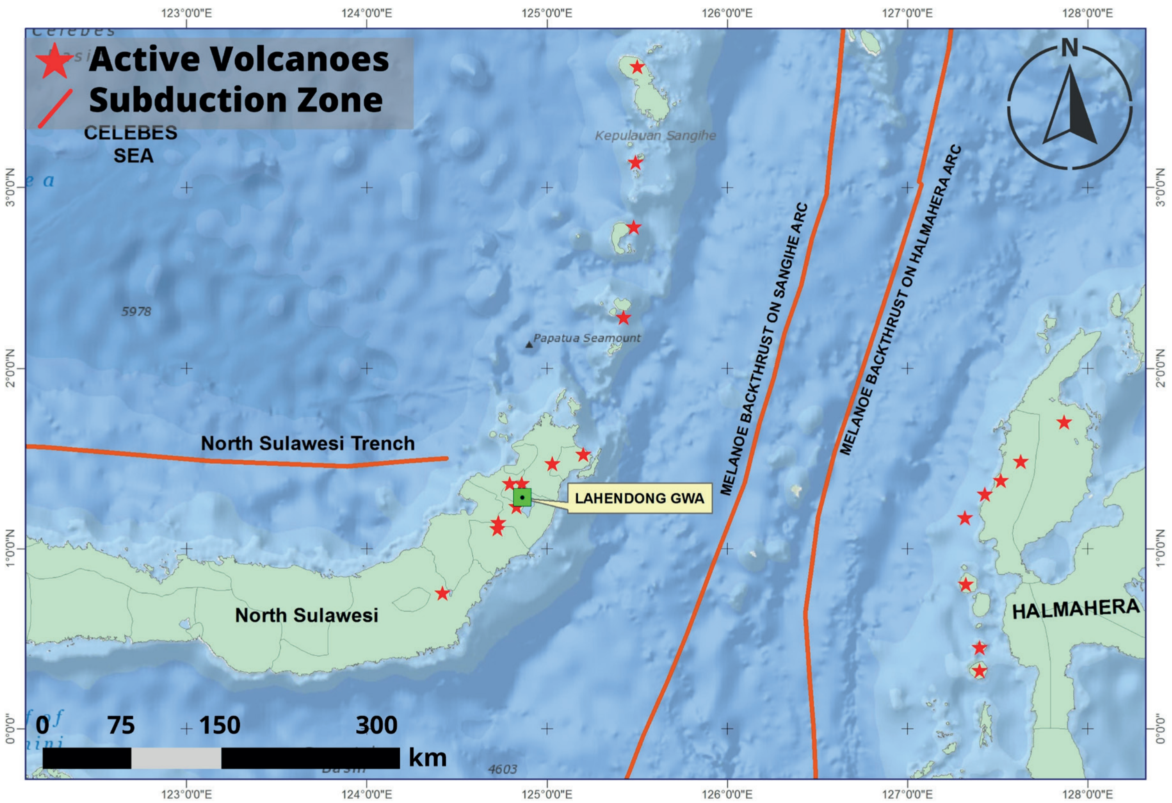

Fig. 1. *Tectonic elements of the Minahasa area (acc. to Siahaan et al. 2005)*

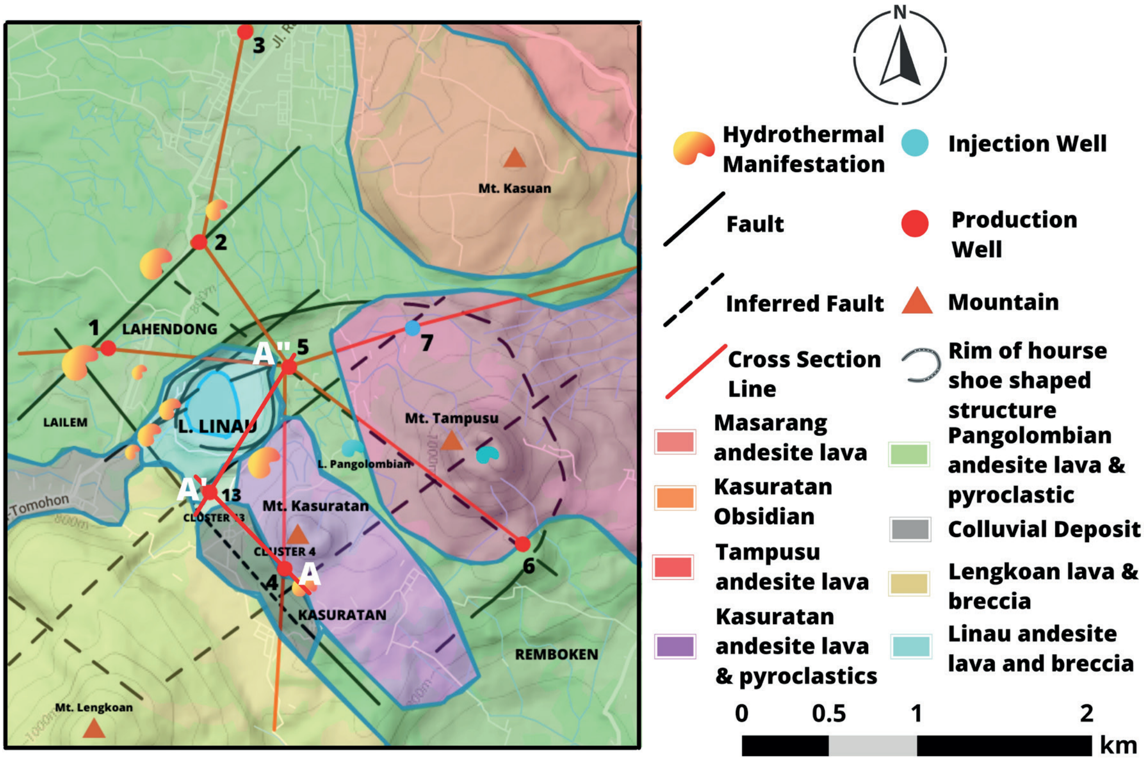

Fig. 2. *Geological map of the Lahendong geothermal field, the North Sulawesi (acc. to Utami et al. 2004)*

Geophysical aspects of the Lahendong GWA

Research on the geophysical features of the Lahendong geothermal field was first done twenty years ago, supplying gravity, resistivity, and magnetotelluric data. The gravity data shows that the value of the bouguer anomaly increases in a northerly direction and varies from 128 mGal in the southern part to 150 mGal in the northern part of the Lahendong geothermal field (Sumintadireja et al. 2001). The regional bouguer map shows that the trend of the synclinal basement is NE–SW with the value of the bouguer anomaly 130–148 mGal northward (Sumintadireja et al. 2001, Utami et al. 2015). Meanwhile, the positive anomaly of about 7 mGal might correlate with the subsurface of a plutonic intrusion which has been found beneath Lake Linau (Utami et al. 2015).

The resistivity data of this area was obtained using the Schlumberger resistivity method. The resistivity map presents an inconsequential result between spacing variables, particularly in areas that have apparent resistivity of less than 10 Ωm. Therefore, it can be concluded that a low resistivity anomaly was surmised to be associated with the electrically conductive altered rocks and acidic fluids at the surface and near surface. This finding may indicate an upflow zone in the system (Sumintadireja et al. 2001). This is also supported by the relatively higher resistivity found in the southwestern and southern areas of the Lahendong geothermal field (Sumintadireja et al. 2001). The magnetotelluric 1D model indicates that the layer is thickening in the direction of the southwest. Consequently, the higher resistivity layer is represented as a reservoir, while the lower resistivity layer will act as a cap rock in which the pressure and propylitic alteration is detected (Sumintadireja et al. 2001).

Meanwhile, the resistive structures of the Lahendong geothermal field have been acquired using 3D magnetotelluric inversion by Raharjo et al. (2010). The 3D magnetotelluric inversion indicated the reflecting reservoir appears in the north at a depth of 500 m and in the south at 1500 m (Raharjo et al. 2010). In addition, an up-dome resistivity structure is located beneath Lake Linau (Raharjo et al. 2010). A non-resistive cap rock overlays the reservoir. The low-resistivity cap position of this rock correlates with the main upflow area. The reservoir outflow runs through geothermal manifestations, including fumaroles and hot springs.

Geochemical aspects and the reservoir of Lahendong GWA

The Lahendong region is grouped into two hydrochemical systems, with pH neutral water and acidic types. The group is based on the fluid's temperature, electrical conductivity, and pH. The first group with high electrical conductivity in the range of 5020–6140 μS/cm, pH in the range of 2.7–3.7, and reservoir temperatures in the range of 200–274°C, defined as a highly acidic form (acid sulphate-chloride) of well water. The acidic water is observed with a high concentration of SO_4 at relatively low temperatures in (and near) Lake Linau (Brehme et al. 2014). Various fluid concentrations increase particular minerals that control the composition of the rock minerals penetrated (Brehme et al. 2016b). The sulphate minerals that are found in fluid-infiltrated rocks have high concentrations of SO_4. Furthermore, the alteration process involves minerals that are exposed to high temperatures and violent fluids. On the other hand, the second group with low electrical conductivities of 1465–2140 μS/cm, moderate pH (4.2–6.5), and 232–341°C reservoir temperatures describe the form of water considered neutral (chloride) (Brehme et al. 2014, 2016a). The neutral water has relatively low salt content in the southern cluster of the geothermal zone.

The northwest wells (below Lake Linau) have wells with highly acidic water, and the neutral chloride water type is identified in the south and the northeast of Lake Linau. The high salinity of the acid water originates from deeper permeable zones, which seemingly lie below Lake Linau as shown in Figure 3. The mean depth of the reservoir was ca. in cluster 24 (the northwest lake Linau), 2000 m b.g.l., in contrast with the average depth of 1500 m b.g.l. for the chloride reservoir in cluster 4, the southern Lahendong geothermal district. Despite the fact that its temperature difference is ~60°C lower than in the southern part, the productivity of the wells is five times higher (Brehme et al. 2016b). The presence of vertically permeable fractures increases fluid movement (Brehme et al. 2016b). These fractures often allow cold surface water to infiltrate into the reservoir, resulting in lower reservoir temperatures. Reservoir water contains water with chloride or acid sulphate-chloride, while the hot springs contain bicarbonate (Brehme et al. 2014).

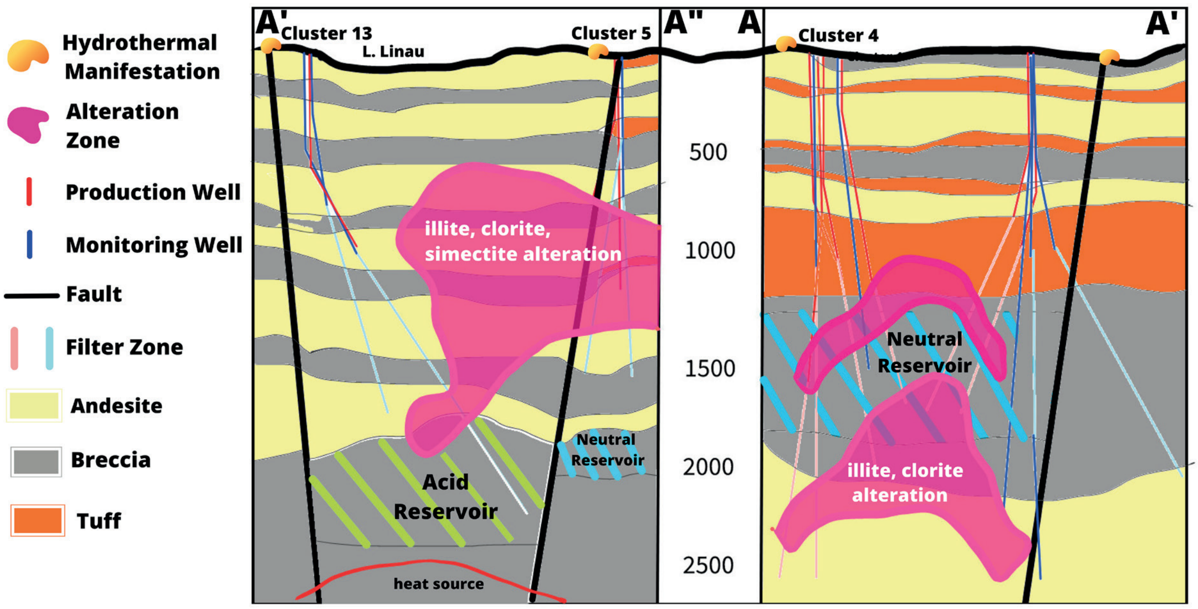

Fig. 3. Conceptual of geohydrochemical model in Lahendong geothermal field (acc. to Brehme et al. 2015). Cross section line presented on Figure 2

Three separate alteration zones define the Lahendong reservoir: kaolinite-anhydrite, epidote-chlorite, and sericite-actinolite (Utami et al. 2011). The kaolinite-anhydrite zone reflects the impact of acid alteration at temperatures of 100–250°C, while the epidote-chlorite zone includes minerals of medium temperature, namely epidote, chlorite, crystalline quartz, calcite, illite, and kaolinite. The sericite-actinolite region is correlated with the intrusion of microdiorite and temperatures between 300 and 350°C (Utami et al. 2015). The Lahendong–Linau block is located in the northern part of the field, covering the Linau crater areas: northwest, inside, and east. The northwest reservoir of the Linau crater is poorly permeable, with acidic, dry steam ranging from 570 to 370 m a.s.l. The reservoir field within the Linau crater has a dry acid vapour layer ranging from 570 to 370 m a.s.l., and the shallow drill hole of the VSI confirms the presence of this layer. The crater is shallow (475–275 m a.s.l.) and deep (from –220 to –1020 m a.s.l.) with hot water reservoirs with good permeability, as confirmed by the LHD-5 well (Brehme et al. 2016a). Second, there is the Lengkoan block, which has medium permeability and two reservoir stages. The shallow and deep reservoirs range between 450 and 250 m a.s.l. and between –150 and –1150 m a.s.l., respectively. In the deep reservoir, the temperature was approximately 350°C. Wells in cluster LHD-4 confirmed the presence of the Lengkoan block (Utami et al. 2007).

Environmental implication in North Sulawesi, Indonesia

Radja & Sulasdi (1995) studied the possibility of the adverse environmental impact of several geothermal power plants in Indonesia. The separated geothermal water not only polluted the water body and atmosphere but also caused thermal pollution. Geothermal wastewater from the Lahendong geothermal field has a temperature of up to 130°C, which is significantly higher than the river water temperature of 28°C (Radja & Sulasdi 1995). The study showed that the river temperature increased to 90°C after mixing with river water, causing thermal pollution (Radja & Sulasdi 1995). Hariyadi et al. (2012) stated that arsenic (As) is produced and released during every stage of the thermal energy process in the Lahendong geothermal power plant, including operation, separation, and condensation (Hariyadi et al. 2012). Fortunately, the geothermal wastewater in the form of brine and condensate with a low temperature in the Lahendong Geothermal power plant is being reinjected into the formations in LHD-7.

According to Hariyadi et al. (2012), an official report of the geothermal power plant in Lahendong from January to June 2012 indicated that As concentrations in wastewater had fluctuated between 1.2 to 1.26 mg/L (Hariyadi et al. 2012). For example, in clusters 4 and 7 (shows at Figure 4), the amount of As was monitored under a standard quality of 0.05 mg/L. Meanwhile, at some locations, such as clusters 5, 13 and 24 (shows at Figure 4), the report said that As concentrations exceeded the standard quality, reaching 1.26 mg/L (Hariyadi et al. 2012). Hariyadi et al. (2012) analysed the feasibility of geothermal wastewater utilisation from the Lahendong geothermal field. The survey showed that the prospective utilisation of geothermal wastewater includes hot showers, steam baths, agricultural purposes, wood drying, tourism, processing of palm sugar, and an alcohol distillery with a potential value price of around IDR 941,934,000/year (60,608 EUR) (Hariyadi et al. 2012). Despite the utilisation potential, the aforementioned study reported that wastewater quality was low and therefore cannot be utilised directly.

A sample of several springs in the Lahendong geothermal field was recently taken and analysed by Brehme et al. (2016b). The sample location is shown in Figure 4. According to Brehme et al. (2016b), concentrations in these springs exceed the recommendation value by WHO and Indonesian Ministry of Health (0.01 mg/L for drinking water and 0.05 mg/L for clean water) (Herschy 2012, Menteri Kesehatan Republik Indonesia 2017), as do the concentrations of As at sampling point M1 (0.044 mg/L) and M2 (0.184 mg/L) (Brehme et al. 2016b). In line with the As occurrence in the hot springs, the concentration in the production well has varied between 0.56 and 3.28 mg/L (Brehme et al. 2016b). Figure 4 shows the location of the samples M1 and M2 where As is found (located close to residential communities). because of this, the potential for water contamination by As in this area is clearly high.

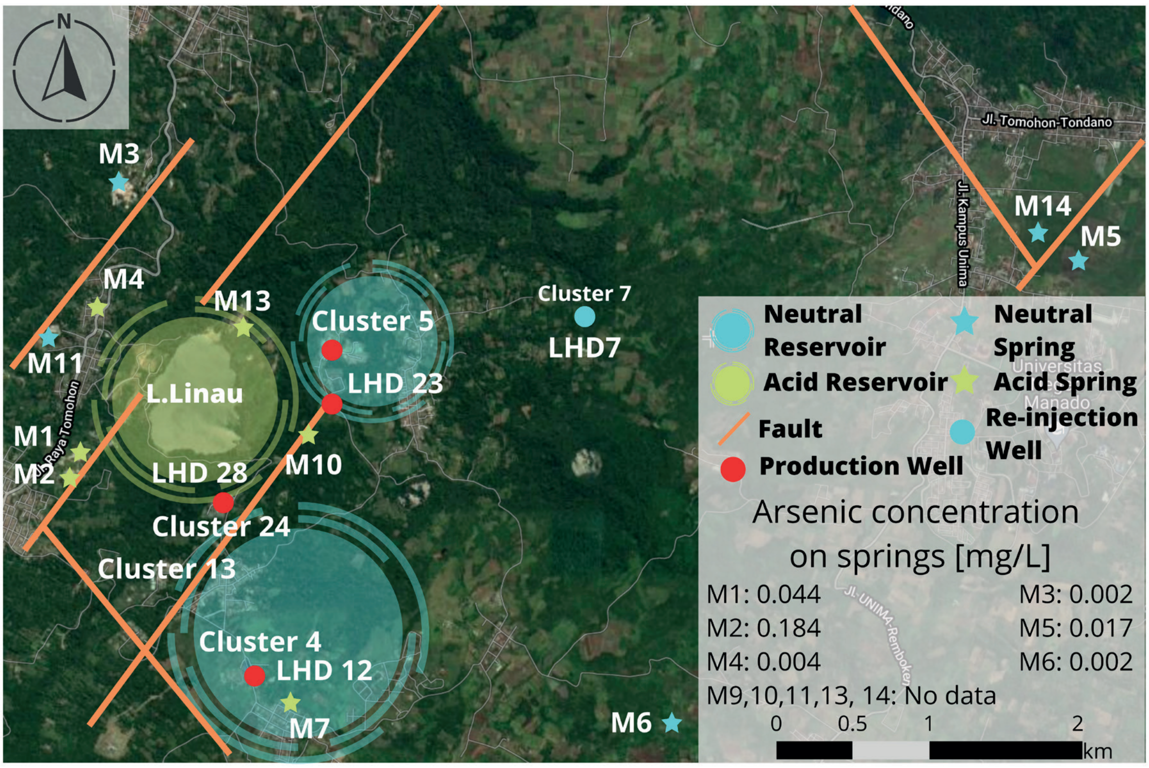

***Fig. 4.** The Location of all clusters, wells, and hot springs in Lahendong GWA (modified by Google Maps, acc. to Brehme et al. 2016b)*

The city of Tomohon, in North Sulawesi, has not only been experiencing water contamination but also has recently suffered from El-Nino-driven droughts. Some sources report that four springs in Tomohon no longer produce water, while other water source flow rates have declined. Generally, people in Tomohon rely heavily on water resources for daily consumption, agriculture, fish farming, and tourism. Although the Lahendong geothermal wastewater in Tomohon is being re-injected, the potential for water contamination by hazardous materials from geothermal power plant activity is still present.

THE RATIONAL USE OF THE GEOTHERMAL RESOURCES IN LAHENDONG GWA

The Lahendong GWA in North Sulawesi province was considered as one of the first geothermal development project in Indonesia where the first exploration was conducted in 1970. The first geothermal power plant was commissioned in 2001 and has been operated and developed until present-day. This section will present information about the geothermal utilisation that have been utilised and its potential utilisation in which could be realised in the near future.

Existing geothermal utilization in Lahendong GWA

As the first geothermal power plant in eastern part of Indonesia, the areas have been studied for other utilisation such as palm sugar production. Moreover, a pilot plant to reuse waste geothermal brine and produce additional electricity using ORC methods were developed.

Lahendong geothermal power plant – installed capacity 120 MWe

PT Pertamina Geothermal Energy has exploited the Lahendong geothermal field in the North Sulawesi since 2000. This geothermal environment is regarded as a hot-water-dominated system (Nugroho 2007). It has an 80 MWe installed capacity in the Lahendong area supplied by more than 8300 tons of steam per day, while the Tompaso area has a 40 MWe capacity (Murakami & Takamiya et al. 2017). There are 46 wells in this area that have been maintained over the last 20 years.

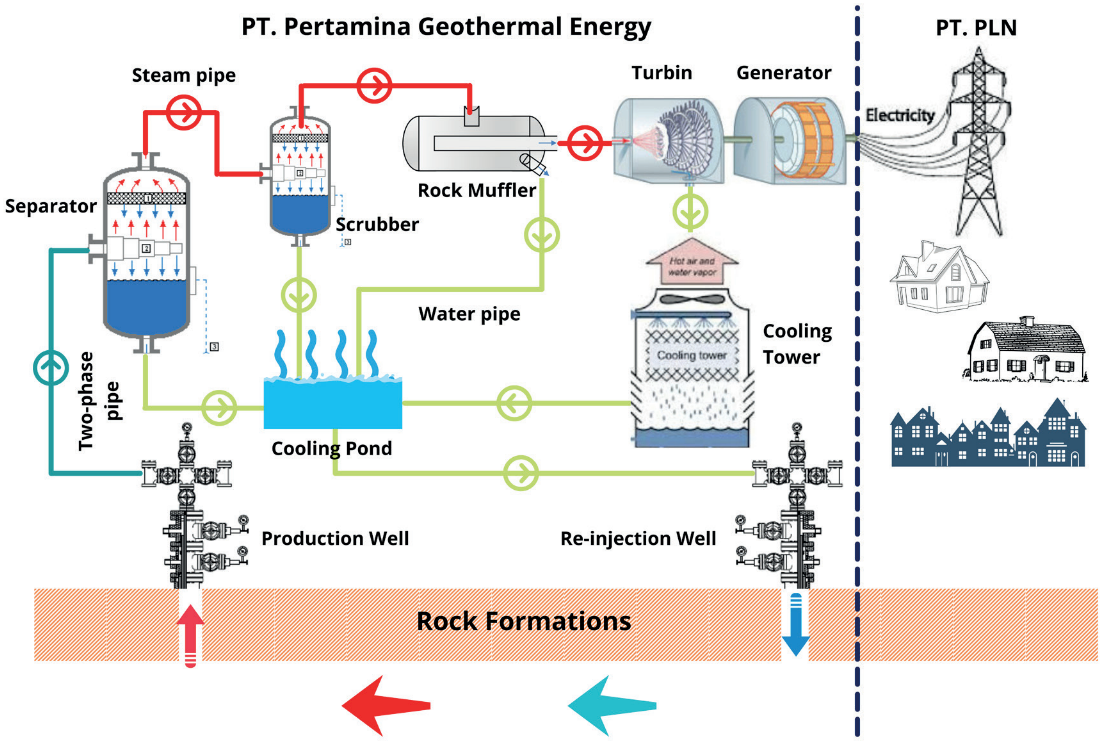

Fig. 5. Schematic flow of Lahendong geothermal power plant (acc. to Yokogawa Electric Corporation 2007, modified)

Until now, this power plant has been supplying approximately 40% of the electricity consumption in Manado, North Sulawesi. Figure 5 illustrates the schematic flow of the Lahendong geothermal power plant. Currently, there are four development clusters in the geothermal sector in Lahendong. Each cluster consists of several wells that provide steam to generate electricity. The borehole clusters are shown in the conceptual of the hydrogeochemical model in Figure 3 and comprise both vertical and deviated wells. As shown in Figure 3, the northern clusters have deviated wells with landing zones below Lake Linau. This lake was considered an acid lake, a reasonable assumption since the reservoir type in this area is water-type sulphate-chloride acid. Meanwhile, the southern part of the Lahendong geothermal field is categorized as the chloride type of water which has spread to the side of Mount Lengkoan and even to the northeast part.

Pilot geothermal binary power plant – installed capacity 500 kWe

As of April 2019, this geothermal binary pilot project plant has successfully operated and generated about 1.6 GWh (gross) with 1.3 GWh of net electricity (Frick et al. 2019). The pilot plant has been combined with the Lahendong geothermal field cluster 5 near the village of Pangolombian. The geothermal brine from LHD-5, with a temperature of 170°C corresponding to a separator pressure of 7.9 bar, was pressurized. The physical-chemical properties of geothermal brine were reported with TDS-content (total dissolved solids) is between 150 and 540 mg/L with a relatively high SiO_2 concentration range from 100 to 500 mg/L, with the pH value of 5–9 (Frick et al. 2015, 2019). In this pilot plant, the integration of the power conversion cycle by using intermediary closed water cycles for heat supply and heat removal was implemented. A subcritical single-stage ORC with internal heat recovery was chosen as the conversion cycle to attain higher reliability. Moreover, N-Pentane was selected as a working fluid which is suitable for the heat source temperature (Frick et al. 2019).

In order to improve the plant reliability and availability, several technical modifications have been implemented since 2017. These include modifications such as adaptations for the high ambient humidity, changes to the prototype turbo-generator, and controlling the hot water cycle (Frick et al. 2019). The operation of the plant is currently limited, and the control of the hot water supply temperature to the ORC-unit was done to meet the consumption needs of the injection pumps nearby. In this binary system, a primary heat exchanger is used to distribute the brine to the hot water cycle during regular operations. Then, in order to heat and evaporate the working fluid in the ORC unit, the heated water is used. A centrifugal pump is used to circulate the hot water continuously. Moreover, an expansion vessel with a nitrogen cushion is pressurized to maintain the pressure of the hot water cycle and the working fluid vapour drives a turbo-generator. Then, right before encountering the water-cooled tubes, the superheated working fluid vapour flows through a recuperator. A dry cooler consisting of 6 units is implemented to remove the heat in the cooling water cycle. The use of a hot water and cooling water cycle made it possible to transport and install a wholly preassembled and pretested ORC unit (Frick et al. 2019).

Palm sugar processing

The Lahendong geothermal field is a geothermal working area that utilises direct geothermal pressure for agricultural production. Geothermal energy investigation for palm wine plantations and palm sugar production has been conducted in this area. A commercial palm sugar production plant of 3500 farmers has been pressurized. This palm sugar plant is managed by a non-governmental organization called Yayasan Masarang with the cooperation of Pertamina Geothermal Energy Lahendong and has a maximal capacity of 12,000 Kg/d. By pressurizing flashed steam from the separated brine, the excess steam supplies the juice heater, evaporator and pan vacuum in which 3000–5000 Kg/d of palm sugar can be produced (Surana et al. 2010a). Unfortunately, due to the low pressure of steam supply of about 1 to 2 bar, the productivity of the plant decreased to 1000 Kg/d in 2011. As a result of high silica in the geothermal brine, scaling on pipes, and some of the equipment employed at this facility, production was often interrupted or even stopped (Roeroe et al. 2013). The schematic diagram of the facility is presented in Figure 6.

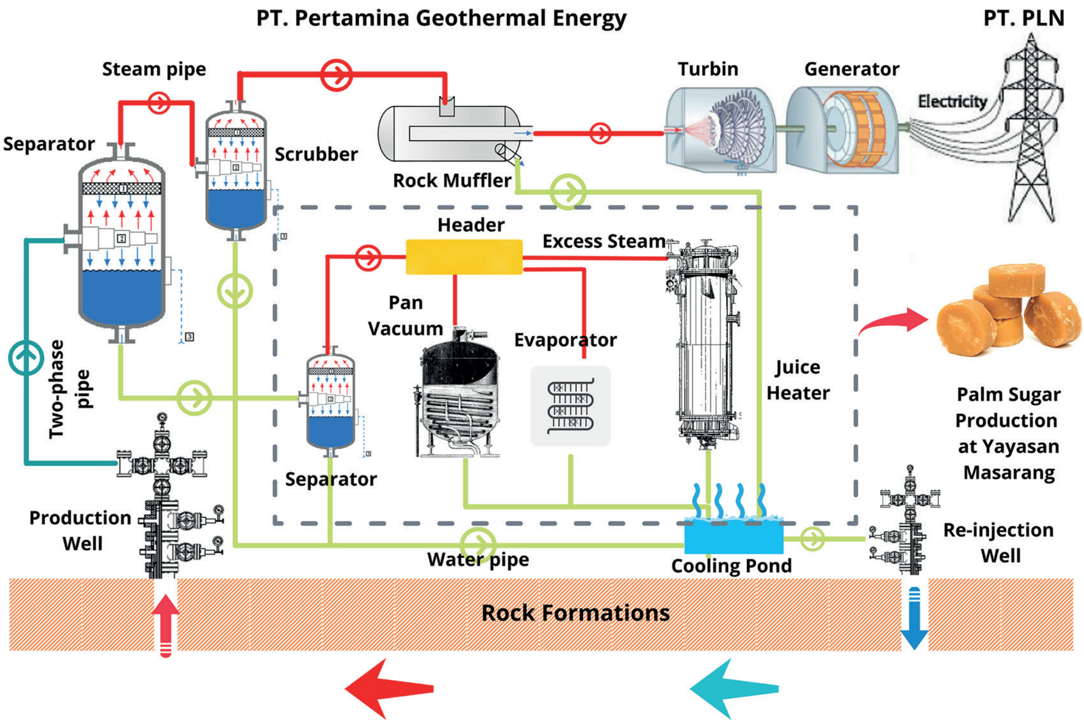

Fig. 6. *Schematic flow of palm sugar production at Yayasan Masarang, Lahendong (acc. to Surana et al. 2010a, modified)*

Potential geothermal utilization in Lahendong GWA

Besides the existing geothermal utilisation facility, the Lahendong geothermal field possess huge potential to be expanded. For example generating electricity from waste heat, coconut meat drying, and geothermal desalination plant.

The alternative binary geothermal power plant from waste heat in Lahendong

The first geothermal binary system to have been successfully implemented is the Lahendong geothermal system. According to Nugroho (2007), the Lahendong unit 3 in cluster 5 is designed to generate 800 t/hr of two-phase brine-steam mixture (dryness 20%) from 4 production wells (LHD-5, LHD-9, LHD-21 and LHD-23). The two separators provide a total steam of 175 t/hr in the steam manifold from this unit. The separated steam is delivered to the power plant through a demister to make the steam dryer before entering turbine power plant unit III. This unit consumes approximately 147 t/hr of steam and generates about 20 MWe (Nugroho 2007).

On the other hand, the separated brine will accumulate in the brine manifold and be reinjected directly back into the formation. Kumolosari et al. (2020) proposed a new design that might be appropriate for pressurization in Lahendong. They suggest using a type of brine with the temperature set to 150°C where the silica scaling index (SSI) is 0.97 (Kumolosari et al. 2020). Those parameters are chosen to prevent scaling and achieve the optimum results. Furthermore, the working fluid in the geothermal organic ranking cycle that he suggests using is R245fa (Kumolosari et al. 2020). Based on the simulation results, the proposed binary system using waste heat will generate electricity of about 2.46 MWe with a net thermal and energy efficiency of 11 and 34%. Besides the proposed design plant, the potential of brine waste pressurized for electricity production includes a flash system with a back-pressure or condensing turbine, the binary cycle with or without regeneration, and the Kalina cycle (Nugroho 2007, Kumolosari et al. 2020).

Coconut meat drying product

In 2003 and 2008, the Agency for the Assessment and Application of Technology Indonesia (BPPT) with PT. Pertamina Geothermal Energy implemented pilot plants with direct geothermal energy use in the Way Ratai Geothermal Field (Lampung Province) for coconut meat (copra) and cocoa drying. The pressurizing of both a shallow natural geothermal well and an artificial one gave good results (Surana et al. 2010a). The North Sulawesi province, where Lahendong Geothermal Field is located, has extensive coconut plantations and corn farming potential. Pertamina plans to pressurize the geothermal steam in Lahendong commercially for the coconut meat and corn drying businesses (Surana et al. 2010b).

However, apart from the existing pilot system, Surana et al. (2010a) and Tesha (2006) studies presented two methods to pressurize geothermal resources for coconut meat drying. First, based on the coconut meat drying plant in Way Ratai, it would consist of a downhole heat exchanger, a drying room, a pump, and a freshwater tank. In this plant, the downhole heat exchanger is placed into a natural geothermal well with a temperature of 80–95°C at a depth of two meters (Tesha 2006). Then, freshwater passes through it before being heated up and delivered to the drying room. The temperature in the drying room must be maintained at 50°C to dry up the coconut meat by a natural draft conductive heat exchange. The quality of the copra manufactured in this facility is much better than the conventional one because there is no smoke contamination (Surana et al. 2010a). The second option is to use brine water obtained from the separator in the power plant. This geothermal brine provides considerable amounts of energy that can be extracted for further pressurization. Temperatures up to 99°C have sufficient heat for a 60°C drying unit. In order to reach the maximum condition, the temperature and humidity have to be maintained inside the drying unit (Tesha 2006). Consequently, the difficulties such as surface hardening and microbial deterioration can be avoided.

The separator in the Lahendong geothermal field produces up to 40,000 Kg of brine every hour. Hence, a large amount of coconut and other crops can be dried depending on market conditions. According to Tesha (2006), approximately 159 drying rounds of the drying process could be performed each year. Consequently, if 14,250 coconuts are dried per drying sequence, about 2.3 million coconuts could be marketed by this drying unit each year. Despite this advantage, the geothermal fluid in this area contains a high silica saturation index (Roeroe et al. 2013). As a result, the potential of silica scaling in the coconut meat drying plant will be high. The silica inhibitors are needed to ensure that the drying unit functions normally. Another option is by regularly injecting pressurized steam through the radiator to clean out the potential silica sediments. Those methods will help to prevent silica scaling.

Water desalination using geothermal energy

Around 33.4 million Indonesians (especially in the east part of the country) (Piesse 2016) still experience water scarcity despite abundant alternative sources. The Indonesian Statistics Center (BPS) (Badan Pusat Statistik 2019) reported that Indonesia's current access to clean water is 72.55%, far below the target established through the sustainable development goals of reaching 100% by 2030 (Ministry of National Development Planning of Republic Indonesia 2015). This target was mandated through the National Medium Term Development Plan of 2015–2019 (Ministry of National Development Planning of Republic Indonesia 2017). Therefore, to achieve these goals and objectives, Indonesia has attempted to cooperate with several parties that could help in overcoming the obstacles hampering such an ambitious target. One way to overcome the water scarcity challenges is to address water desalination using geothermal energy ("thermal desalination" hereinafter). Geothermal sources are beneficial (nearly ideal) for the thermal desalination process because the energy output is stable with fewer intermittent problems. Moreover, it offers mature and uninterrupted thermal energy compared to other renewable energy resources, which are not affected by seasonal changes such as weather fluctuations (Gude 2016). Another advantage is that geothermal water can serve as both a feed and heat transfer medium for desalination (Tomaszewska & Bodzek 2013a, Gude 2016). Geothermal desalination is considered to be cost-effective and environmentally friendly compared to other renewable energy sources (Tomaszewska & Bodzek 2013b). A viable geothermal desalination application must meet several criteria (e.g., availability source of geothermal energy at low cost), have impaired source water that can be processed via one or more pre-treatment and desalination processes, and have a suitable user or market for product water to justify the investment and operating costs.

Thermal desalination is also considered a direct application of geothermal energy sources. This application remains underestimated owing to its quite low utilisation, despite the abundant resources available. A high-pressure geothermal source allows the direct use of shaft power in mechanically powered desalination, whereas high-temperature geothermal fluids can be used to produce electricity for reverse osmosis (RO) or electrodialysis (ED) plants. In this technology, geothermal energy sources play a significant role in supplying heat sources. Moreover, geothermal energy can produce water and electricity simultaneously through a cogeneration scheme and poly generation, which involves both heating and cooling applications with various benefits (Tomaszewska & Bodzek 2013a, 2013b, Turchi et al. 2015, Gude 2016). Therefore, it can be analysed that the potential for geothermal desalination is quite high in the Lahendong geothermal working area, because of electricity production from a renewable source with a capacity of 120 MWe. The following geothermal desalination options may be considered: (1) membrane process such as RO and ED – in this case, electricity may be partially used to operate the desalination plant. Further, feed water sources could be water from the cooling pond or hot springs in the area of Tomohon; (2) thermal processes such as multi-stage flash distillation (MSF), multiple-effect distillations (MED), and membrane distillation (MD) – in this case, the geothermal water may be used as a thermal source and feed water source, where the electricity produced will provide electrification for some of the desalination equipment that requires electrical energy, such as pump systems.

To determine the most appropriate desalination technology for freshwater production, a number of parameters have to be considered such as the physicochemical properties, type of required energy, type of feed water, beneficial-use criteria, brine and concentrate disposal options, and technical and community readiness. Therefore, there is a need for comprehensive studies such as physicochemical analysis with water samples from several locations (wells, separator, cooling pond, hot springs, and groundwater) that can be used to determine their mineral concentrations, gathering data such as the capacity factor of the Lahendong geothermal power plant, and flow rate capacity. What is more, an economic analysis will be an essential aspect to determine whether a desalination plant is economically sound. Such aspects will be analysed and presented in future publications.

CONCLUSIONS

Geothermal energy potential in Lahendong, Indonesia is considered extensive because of the characteristics of the high-temperature reservoir (200–340°C) and the high flow rate production of steam and water. The actual utilisation of geothermal energy in the Lahendong geothermal working area consisted of electricity production with a total capacity of 120 MWe from a four-unit power plant using a flashed system. Moreover, the only example of a binary geothermal power plant in Indonesia with a capacity of 500 kW was commissioned in 2019. Besides electricity production, a direct utilisation of geothermal brine was in palm sugar production that can produce from 3000 to 5000 Kg/d. Nevertheless, due to the high silica content in the brine, this palm sugar plant stopped operating. Besides the actual utilisation, this geothermal field provides another potential utilisation that might be developed in the near future, such as power production from geothermal waste heat and coconut meat drying.

However, the environmental analysis showed that water contamination and the water scarcity problems in Tomohon, North Sulawesi, are severe. Although Lahendong geothermal wastewater is being re-injected, the potential for water contamination by hazardous materials from geothermal power plant activity still exists. Consequently, implementing geothermal water desalination in the future would be beneficial for both geothermal companies and local communities.

The geothermal resources in Lahendong provide prospects for both the membrane and thermal processes of desalination technology. However, geothermal desalination using the thermal process is more appropriate than the membrane process because the electricity produced from the Lahendong geothermal power plant can provide a significant impact if it is used for the electricity grid in North Sulawesi. Therefore, the most appropriate thermal energy scheme for the desalination process of the Lahendong geothermal working area is to use the outlet brine of the Lahendong geothermal power plant as the thermal energy source and feed water source.

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