COFFEE DRYING SYSTEM DESIGN FOR GEOTHERMAL DIRECT USE APPLICATION IN FLORES ISLAND

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Keywords: *Geothermal Direct Use, Coffee Drying System, Dryer, Shell and Tube, Piping Material, CO_2 emission reduction.*

ABSTRACT

Mataloko is one of the areas in Ngada District, East Nusa Tenggara Province where there is a geothermal power plant operating with 2.5 MW capacity. The type of reservoir is brine-dominated. In addition to geothermal sources from the powerplant, there is a geothermal resource that is coming from surface manifestation around the powerplant. Moreover, Mataloko is not only a geothermal area but also an agricultural and plantation area where coffee is the biggest plantation commodity with the cumulative harvest in every year reaching 3,000 tonne. Current practice for drying the coffee fruit or cherry on the open air (conventional) is a challenge for farmers. This practice cost and requires significant time for producing high quality green beans. A geothermal direct use of drying system has been designed for coffee commodity in Mataloko. The drying system scheme utilizes a Shell and Tube type of Heat Exchanger to produce 50^{o}C for the final air temperature. Meanwhile, this system will use Tray Dryer with capacity of 500 kg. At this capacity, the energy required by the dryer is 240 kWh per 500 kg batch (8 hours). The amount of energy from the dryer will save 0.18 metric tons CO_2 emission per 500 kg batch that equivalent to CO_2 emissions from the same drying process when compared to diesel fuel.

1. INTRODUCTION

Indonesia is one of the countries in the world with the greatest geothermal energy potential. This is because Indonesia consists of islands that surrounded by hotspots. With that reason, Indonesia is known as “Ring of Fire” country. The potential utilization of geothermal energy as renewable energy is exceptionally large to be implemented. According to the ESDM (ESDM, 2020), the geothermal potential in Indonesia reaches 23,900 MW(e). Meanwhile, the implementation from that amount is only 2,130.6 MW(e) or 8.9%. This number is still very low because until 2020, geothermal utilization in Indonesia is below 10%.

One of the locations with largest geothermal potential in Indonesia is Flores Island. Flores Island has a potential of 902 MW of geothermal resources. There are sixteen geothermal locations in Flores Island including Waisano, Ulumbu, Wai Pesi, Gou-Inelika, Mengeruda, Mataloko, Komandaru, Ndetusoko, Sokoria, Jopu, lesugolo, Oka Ile Ange, Atedai, Bukapiting, Roma-Ujelewung and Oyang Barang. Based on those locations, Mataloko is the location that has installed a powerplant with 2.5 MW capacity since 2011. However, the powerplant condition in Mataloko is not operating nowadays. Because of the utilization of geothermal sources for electricity needs cannot be used at this time, then applying it as a geothermal direct use is the best option.

The objective of this study is identifying the plantation commodities that can be applied for geothermal direct use in Mataloko. Other than that, understanding about the condition of geothermal resource is very important. This is because some of the parameters (e.g., temperature) will influence to the commodities that will be applied. Moreover, identifying about the result of coffee drying system design is going crucial. This result is how much energy is required for drying the coffee using geothermal energy at certain capacity. Eventually, after knowing the amount of energy from coffee drying capacity, identification can be made regarding how much CO_2 emissions can be saved from the use of geothermal energy for coffee drying.

2. METHODOLOGY

Identifying the plantation commodities in Mataloko is the first step of this study. Based on the data from BPS (BPS Kecamatan Golewa, 2020), coffee is the biggest production in Golewa district and has a big impact to the community. Other than that, coffee commodity can be implemented for the drying. So, on this case coffee has been chosen for geothermal direct use in Mataloko which will be implemented as coffee drying system.

Thereafter, a selection for geothermal heat source that could be used is carried out, whether it be sourced from the wells in the powerplant or coming from surface manifestation. The selection is very depending on the several parameters (e.g., temperature, flowrate, H_2S gas concentration). After that, the designing of coffee drying system is needed. The design includes process flow diagram (PFD), selection of equipment and the calculations. The result of this design is the number of the flow rate and the energy required to supply the coffee drying system needs.

CO_2 emission calculation is the last step in this study. CO_2 calculation is conducted to find out how much CO_2 emission will produce from the use of geothermal heat source. Approach to do is with convert the energy required for coffee drying system capacity in kWh which then calculated to get the value of CO_2 emission in metric tons.

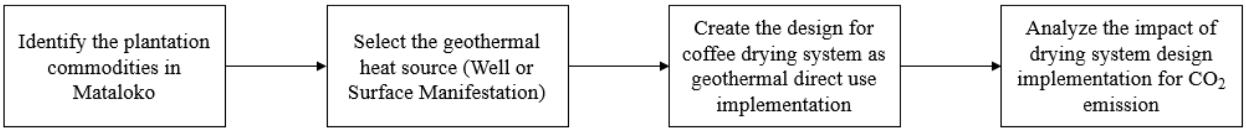

Figure 1: Methodology Flowchart

3. POTENTIAL OF GEOTHERMAL DIRECT USE APPLICATION IN MATALOKO

3.1 Local Commodities

Mataloko sub-district is located in Golewa district as the administration region. Golewa district known as one of the regions in East Nusa Tenggara with high production of plantation local commodities. Coffee is the biggest local commodities in Golewa. This is because the location of Golewa district is including the highland area. According to the Figure 2, coffee is the highest production of plantation commodities in Golewa with 854 ton in 2018. Moreover, in 2019, the production of coffee was still the highest production among other plants. Therefore, it can be concluded that coffee is the biggest plantation commodities in Golewa.
Meanwhile, the definite reason on decreasing coffee production in Figure 3 from 2018 to 2019 was unknown. But it could be because the data obtained was in different resource. And based on the interview with the local government, they were focusing on other commodities.

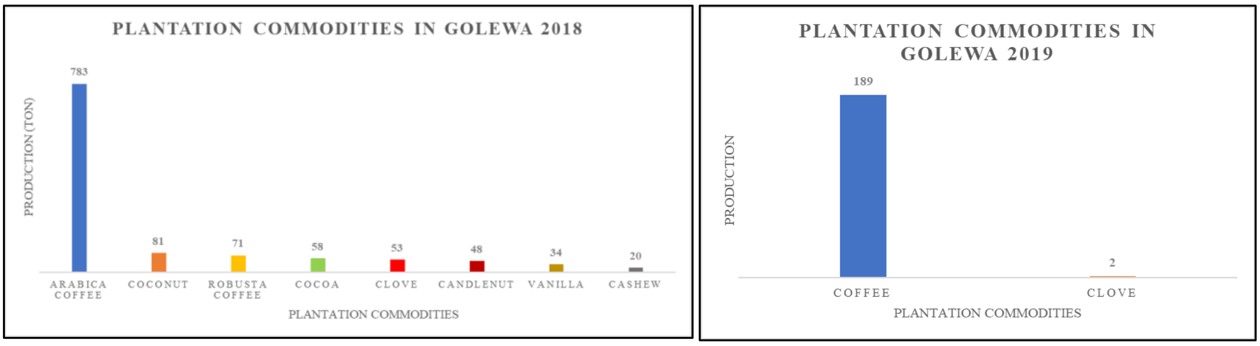

Figure 2: Plantation Commodities in Golewa District 2018 (Ngada, 2019) and 2019 (BPS Kecamatan Golewa, 2020)

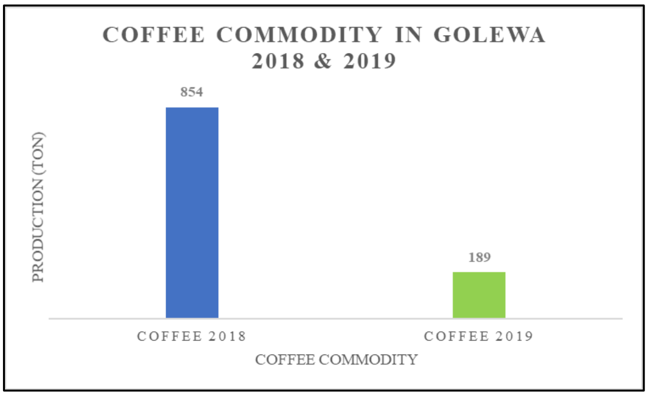

Figure 3: Coffee Commodity in Golewa 2018 (Ngada, 2019) and 2019 (BPS Kecamatan Golewa, 2020)

Regarding for the implementation of direct use program in Mataloko, coffee as the plantation commodities in Golewa is the most appropriate applications for drying. The drying method have an impact for reduce the water content which contain in coffee. By reducing the water content, the quality of coffee is expected to be better and can be stored for a longer period.

3.2 MPIG Flores Bajawa Arabica Coffee

MPIG Flores Bajawa Arabica Coffee is a representative institution for Bajawa and Flores Island community whose role to maintain the production and quality of arabica coffee. This institution consists of 128 UPH (Unit Pengelola Hasil) in which there are 1,000 of farmers. MPIG Flores Bajawa Arabica Coffee is covering three districts: Bajawa, Golewa, and West Golewa. This institution is able to produce the coffee in Ngada Regency up to 3,000 tonne cumulatively in a year. According to the farmers, they are using the conventional method for coffee drying. To produce the best quality of coffee beans, the coffee must be drying until the moisture content become 12%. Meanwhile, it takes 20-25 days in fine weather to get the number of moisture content through the conventional drying. This period of time is needed to dry 500 kg of cherry beans.

However, if the weather is not fine, then the farmers must dry the coffee in the coastal area in the south of Flores Island. Therefore, to take them there, they will need to spend other additional costs for some rental such as car rental, drying land rental and others.

If the implementation of geothermal direct use for coffee drying successfully applied, hopefully this will give impact for the MPIG Flores Bajawa Arabica Coffee, especially for the farmers, to not to spend another additional cost and travel to the coastal area in the south of island, where the location is quite far away.

4. DRYING SYSTEM DESIGN

4.1 Heat Source

There are 5 production wells in Mataloko that are called A-1, A-2, A-3, A-4, and A-5 respectively. However, the only production wells that still can produce steam is A-4 well. This well is located near the main roads, but it needs rework on its wellhead and cellar.

Other than the production wells, there are also 2 surface manifestations called Wae Luja Hot Stream and Ratogesa (Wogoalo) Mud Pool. There are no access and infrastructures leading to Wae Luja Hot Stream and its steam appears randomly as well as it changes locations occasionally. The Ratogesa Mud Pool manifestation is in the form of a big crater that emits H_2S and is very active.

Based on the data above, it can be concluded that the most feasible heat source for this project is the A-4 well. The location can be reached easily by the personnel. The leaks on the wellhead can be reworked easily to provide heat source for the geothermal direct use application for many years to come. A-4 well has the potential of 0.036 tons/hr of brine with temperature in 102^{o}C and enthalpy of brine is 656 kJ/kg. The pressure gauge at wellhead in A-4 is 4 bars.

4.2 Drying System

Based on the heat source available and the required temperature of coffee drying process, the Process Flow Diagram (PFD) for Mataloko geothermal direct use application can be seen on Figure 4.

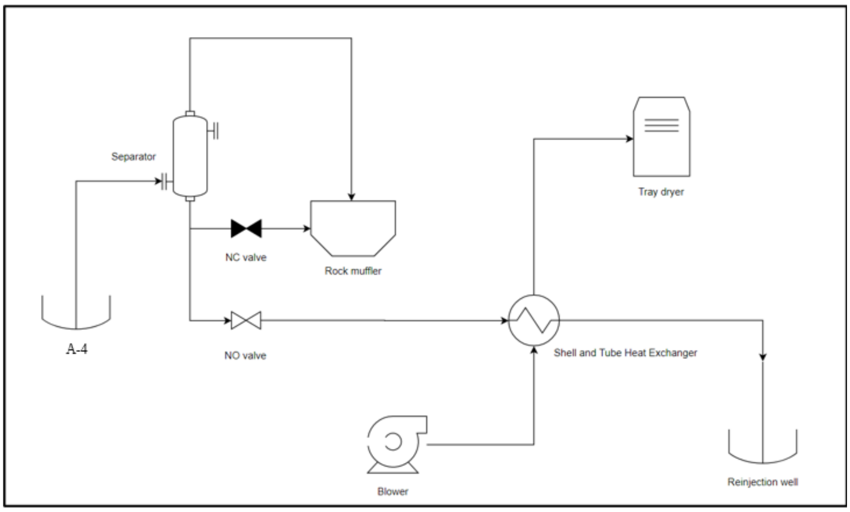

Figure 4: Process Flow Diagram

This direct use application will utilize the brine from A-4 production well to dry coffee beans. The brine from the well will be separated by the separator, where the steam separated in this equipment will be released with a Rock Muffler (RM). This steam is not used for the direct use application because it is projected to be used by the Mataloko Powerplant when the power plant has finished its reparation. The drying media used for the coffee drying process is air, which are blown by a blower through a heat exchanger where its temperature rises to 50^{o}C. The brine will be reinjected to the reservoir by an injection well after it passes through the heat exchanger.

4.2.1 Heat Exchanger

There are some selection parameters in selecting the heat exchanger, which are the working fluids phase, the working temperature and pressure, maintenance difficulties, equipment dimensions, and the capital cost. The types of heat exchanger that will be compared are the double pipe, shell and tube, finned tube, and the plate and fin heat exchanger, with its comparison can be seen on Table 1.

Table 1. Comparison of Heat Exchanger Type

Type of Heat Exchanger	Working Fluid	Temperature and Pressure	Maintenance	Dimension	Cost
Shell and tube	Liquid & Steam	Flexible	Relatively easy	Medium	Medium
Double pipe	Liquid & Steam	Flexible	Easy	Relatively long	Cheap
Finned tube	Liquid & Steam, generally steam on the fin	Normally on low temperature	Difficult	Small	Medium
Plate fin	Liquid & Steam on the pipe and steam on the plate	Normally on low pressure	Difficult	Small	Expensive

As the area provided for the heat exchanger is quite narrow in Mataloko, it can be concluded that the most suitable type of heat exchanger used is the shell and tube. Shell and tube have been chosen due to relatively easy for maintenance and working fluid can accommodate liquid and steam. Furthermore, shell and tube have flexibility of temperature and pressure that will be used, and the cost is relatively medium.

For technical calculations of heat exchangers, we were using LMTD (Logarithmic Mean Temperature Difference). The LMTD approach utilizes a logarithmic approach to determine the temperature difference between hot and cold part fluids. The greater the LMTD value, the more heat is transferred from the two fluids. Equations (1) and (2) are used in this approach.

$$LMTD = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)} = \frac{\Delta T_A - \Delta T_B}{\ln \Delta T_A - \ln \Delta T_B} \quad (1)$$

$$Q = U\ x\ A\ x\ LMTD \quad (2)$$

Where:

ΔT_A : Temperature difference in A side, K

ΔT_B : Temperature difference in B side, K

U : Overall heat transfer coefficient, W/m^2K

A : Contact surface area, m^2

Based on the calculation using Equation (1) and (2), the shell and tube specification can be seen on Table 2.

Table 2. Shell and Tube Design Result

Shell and Tube Heat Exchanger				
	Parameter	**Unit**	**Brine (Tube Side)**	**Air (Shell Side)**
Line Sizing	Dimension	mm	Outer Diameter: 26.7 Inner Diameter: 20.96 Length: 2000 1,25 pitch/diameter	Inner Diameter: 320
	Mass flow	kg/s	3.5	1.56
	k	W/m.K	52 (Carbon Steel 0.5% C)	
Calculation	Fluid Velocity	m/s	0.46	21.86
	U	$W/m^2.K$	50.5	
	Number of pipes in 1 bundle	pipe	90 (4 tube passes)	
	Pressure drop	bar	0.023	0.00002
	Overdesign	%	1.01	

4.2.2. Dryer

In this dryer selection section, 3 types of dryers will be explained, namely Tray Dryer, Bed Dryer and Rotary Dryer. In addition, several considerations in the selection of dryer are explained, including: 1). Operation mode (Continuous/batch), 2). Contact with air (direct/indirect), 3). Static or Dynamic, 4). Drying capacity, 5). Drying time, 6). Cost, and 7). Ease of Use. The following table contains considerations of drying selection:

Table 3. Consideration of Drying Selection

Parameters of Consideration	Type of Dryers		
	Tray Dryer	**Bed Dryer**	**Rotary Dryer**
Operation mode (Continuous/batch)	Continuous or batch	Batch	Continuous or batch
Contact with air (direct/indirect)	Direct	Direct	Direct
Static or Dynamic	Static	Static	Dynamic
Drying capacity	Small capacity	Tend to be more of a small capacity	Large capacity
Drying time	Long duration	Long duration	Short Duration
Cost	Tentative	Tentative	Expensive
Ease of Use	Easy	Easy	Difficulty

From the description of Table 3 above, it can be concluded that the drying selected is the Tray Dryer. This is due to the consideration of several parameters such as relatively smaller production capacity that can be adjusted to the needs, relatively low cost, and easy to operate for the community.

4.2.2.1 Dryer Calculation

In this drying calculation section, the calculation will be carried out using the heat mass balance method, namely by reviewing the dryer that will be used as a black box. The parameters that will be considered are the input and output of the air entering and leaving the dryer and the water content contained in the coffee. Some of the assumptions that will be used are the weight of coffee to be dried is 500 kg of ripe green coffee, the working fluid used is air at a pressure of 1 atm, the process of heating the air that occurs in the heat exchanger is sensible heating, the drying process is carried out adiabatically with the target of maximum relative humidity and drying time in a day is 8 hours.

To determine the target of this drying process, the initial moisture content of the coffee to be used and the environmental conditions at the drying location must be known. The type of coffee to be dried is the type of Arabica coffee (*Coffee arabica L.*) which grows in Mataloko highlands. Based on a study conducted by (Chandrasekar V & Viswanathan R, 1999), Arabica coffee that has gone through the washing process and is in the form of parchment coffee has an average water content of 60.9%. This water content can be used as a reference in drying calculations so that it can be seen the amount of air needed to dry 500 kg of coffee. Furthermore, it is also necessary to target the water content to be achieved in coffee drying. Referring to (Indonesia Patent No. 2907:2008), green coffee beans that are ready to be packaged and stored must have a water content of 12.5%. For environmental data, it was found that the average temperature in Mataloko was 23.8^{o}C and the average humidity was 61%.

First, we must determine the relative humidity of the air after it leaves the heat exchanger. It is assumed that the process of heating the air in the heat exchanger only uses sensible heat, then in a psychometric diagram the state level only moves to the right towards the desired temperature. The ambient air is heated with the target air temperature required for coffee drying which is around 50˚C (Ghosh P & Venkatachalapathy N, 2014). The heating process that occurs in the psychometric diagram and the state of the air before and after the heat exchanger can be seen in Figure 5 i.e., the process from point A to point B. As for the drying process that occurs in the tray dryer, it can be seen in process B to C. After knowing the humidity of the air after the heat exchanger, then the drying process is continued adiabatically with the target of maximum relative humidity in the tray dryer. For the air properties that take place at each point, see Table 4.

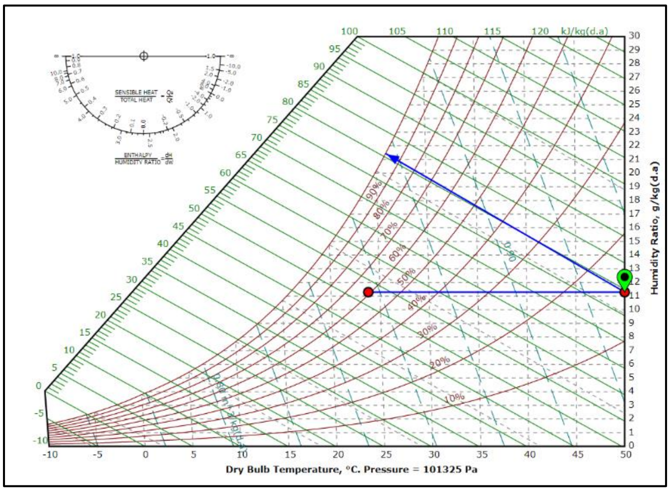

Figure 5. Psychometric Diagram (Fly Carpet Inc, 2021)

Table 4. Air Properties

Psychometric Properties of Air at Each Point			
Parameter	**Before Heat Exchanger**	**After Heat Exchanger/ Before Drying Process**	**After Drying Process**
Temperature	23,8ºC	50ºC	26ºC
Relative Humidity	61%	15%	100%
Moisture content	0,0114 kg water/kg dry air	0,0114 kg water/kg dry air	0,0214 kg water/kg dry air
Enthalpy	54,25 kJ/kg dry air	82 kJ/kg dry air	82 kJ/kg dry air

From the data obtained, the maximum capacity of water that can be evaporated is obtained by reducing the moisture content of the air before entering the tray dryer and saturated air during the drying process.

$$\Delta\omega_c = \omega_{c2} - \omega_{c1} \quad (3)$$

The maximum water capacity that can be evaporated from the coffee is 0.01 kg water/kg dry air. This data is the reference to find out how much air mass rate is needed to dry 500 kg of coffee.

In addition, the amount of water you want to reduce from coffee must be known in units of mass. The value of the water content to be evaporated from 500 kg of coffee beans can be known by subtracting the moisture mass before and after the drying process and obtained 276.57 kg of water that must be evaporated to reach a water content of 12.5%. Then by dividing the value of the amount of water that can be dried and the drying capacity that can be done, it can be obtained the amount of dry air needed.

$$Dry\ air\ needed = \frac{\Delta M_{water}}{\Delta\omega_c} \quad (4)$$

Assuming that the drying process in a day can be carried out for 8 hours, then the mass rate of air required to dry coffee is 3456 kg/hour or about 0,96 kg/s. By using the margin for the design of the dryer to reach 15%, can be concluded that the mass flow rate of air required to dry coffee for 8 hours a day is 1.1 kg/s. Meanwhile the energy rate required for drying 500 kg of coffee is 240 kWh.

5. CO2 EMISSION

Based on the calculation of coffee drying system design, energy rate required to drying the 500 kg of coffee is 30. kW. If the energy converted to hour rate, then in one hour, the energy needed is 30. kWh, but this maintained for 8 hours so the total energy is about 240 kWh. So, refers to the regulations (Environmental Protection Agency, 2020) and (AVERT, 2019) the emission factor for CO_2 is:

$$Emission\ Factor = 1{,}562.4\,\frac{lbsCO_2}{MWh}\ x\ \left(4.536\ x\ 10^{-4}\,\frac{metric\ tons}{lb}\right) x\ 0.001\ \frac{MWh}{kWh} \quad (5)$$

$$Emission\ Factor = 7.09\ x\ 10^{-4}\ \frac{metric\ tons\ CO_2}{kWh} \quad (6)$$

Based on Equation 4, the emission of CO_2 that can be saving from 240 kWh is 0.17 metric tons CO_2 or about 170kg

CONCLUSION

Coffee commodity become the most suitable of commodity that can be applied for the geothermal direct use application in Mataloko. The highest of cumulative production in every year for local commodities, most people are coffee farmers and the suitability of temperature with geothermal heat source from well A-4 in Mataloko Powerplant are some considerations in selecting coffee commodity. The A-4 is the only well in the PLTP Mataloko that can supply the needs of a coffee drying system designed with a capacity of 500 kg. The problem is in the flowrate of brine from Well A-4 which is only 0.036 tons/hour. This is due to the well that did not reach the reservoir target thus the current condition of the well is in steam pocket. However, the temperature that comes out of the well is 102.4ºC. With this temperature, it is still able to accommodate the drying requirement of 50ºC.

Regarding with the drying system, a shell and tube type heat exchanger will be used. Meanwhile, the dryer that will be used is a tray dryer. The calculation results of the tray dryer show that assuming the drying process is carried out for 8 hours, the air flow rate required to dry coffee with a capacity of 500 kg is 1.1 kg/s. Moreover, the energy required for drying 500 kg of coffee is 240 kWh. With the energy produced, it also obtained the CO_2 emission that can be saved using geothermal energy is 0.17 metric tons per hour. The coffee drying system for the Mataloko community will become a real hope for them and the Flores Island community in implementing direct use geothermal development in Indonesia.

ACKNOWLEDGEMENTS

This study could not have been possible without help from our Rigsis team, Annisa, Yuzar and Mikkel. We have been working on this study for 5 months with great effort and high spirit. We also would like to thanks to Mr. Farhan and Mr. Gilang for his guidance on this study. Furthermore, we also thanks to UNDP and EBTKE parties for having the opportunity to present a theme about utilization for geothermal direct use in Flores Island.

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ISSN 2703-4275