

Study on Cascaded Direct Use Application Using Geothermal Fluids in Wayang Windu

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ABSTRACT

The energy from the brine at Wayang Windu geothermal power plant that is coming from the separator can still be utilized prior to reinjection. Tapped brine at 3.33 kg/s flow rate and 149 °C at output system will flow to cascading system consisting of several application, arranged in order from high to low temperature based on the application. The selection of direct use application was based on best potential commodities in Pangalengan region using Analytical Hierarchy Process (AHP) method. From the nine potential commodities, the three applications with the highest rank selected were coffee drying, chicken egg hatching, and tilapia aquaculture pond. The optimum parameter for coffee drying is 50°C for temperature with 12% moisture content. Whereas chicken egg hatching consist of two rooms which temperature is maintained at 40°C, each with relative humidity of 55% and 70%. For tilapia aquaculture pond, water temperature kept at 30 °C. Based on the thermodynamic calculation, the energy needed for each application is 38.39 kW for 1,000 kg coffee, 47.32 kW for 1,000 chicken eggs and 33.46 kW for 400 kg tilapia fish. Therefore, the energy required for whole cascading system is 119.17 kW.

1. INTRODUCTION

Direct use of geothermal energy in Indonesia has long been applied in bathing pools, mushroom cultivation, palm sugar production, etc. All these applications utilize fluid coming from various geothermal heat sources. The energy sources for direct use are coming from manifestations, waste heat power plant, non-commercial wells, or shallow drilled wells in the form of brine or steam. The purpose of this study is the utilization of waste brine at the separator as the thermal energy source.

A number of developed geothermal fields in Indonesia are liquid dominated fields with significantly high temperature injection fluid (>140°C). The brine utilization is still able to be optimized with limitation of temperature injection. One of the idea for optimizing the utilization is cascading system. Parallel with the geothermal development, this study also creates added value to the potential commodities in the selected area.

The area of the study is located in Wayang Windu geothermal field, which is about 50 km from Bandung City, West Java. Wayang Windu working area located in several sub-district. As the study area, Pangalengan sub district was selected due to its distance to the Wayang Windu power plant is closest. The objective of this study is to design direct utilization of geothermal energy with cascading system near to Wayang Windu geothermal power plants. To achieve the objective, there are several steps to be included such as to identify the aspects that influence the selection of direct use applications, to determine the direct use application in accordance with identified aspects, to design a cascading system which consists of selected applications, to analyze the energy balance and conversion process of a cascading system.

2. METHODOLOGY

This study was started by reviewing the Lindal diagram, design parameter of direct use and development of direct use. Furthermore, data collection was conducted to obtain parameters of brine, information about the socioeconomic and description of spatial data at Pangalengan sub-district. All the collected data were analyzed to conclude potential direct use application and recommended area of direct use implementation. The potential direct use application will be selected using the decision making method. The decision making method ranks each potential application based on criteria that affecting the feasibility of direct use implementation. The top three applications were selected as a part of cascading system. The process design of cascading system will produce schematic design and heat balance analyses. However, the process design shall consider the minimum injection temperature to avoid scaling formation and interfere power plant. Figure 1 shows the methodology of this study.

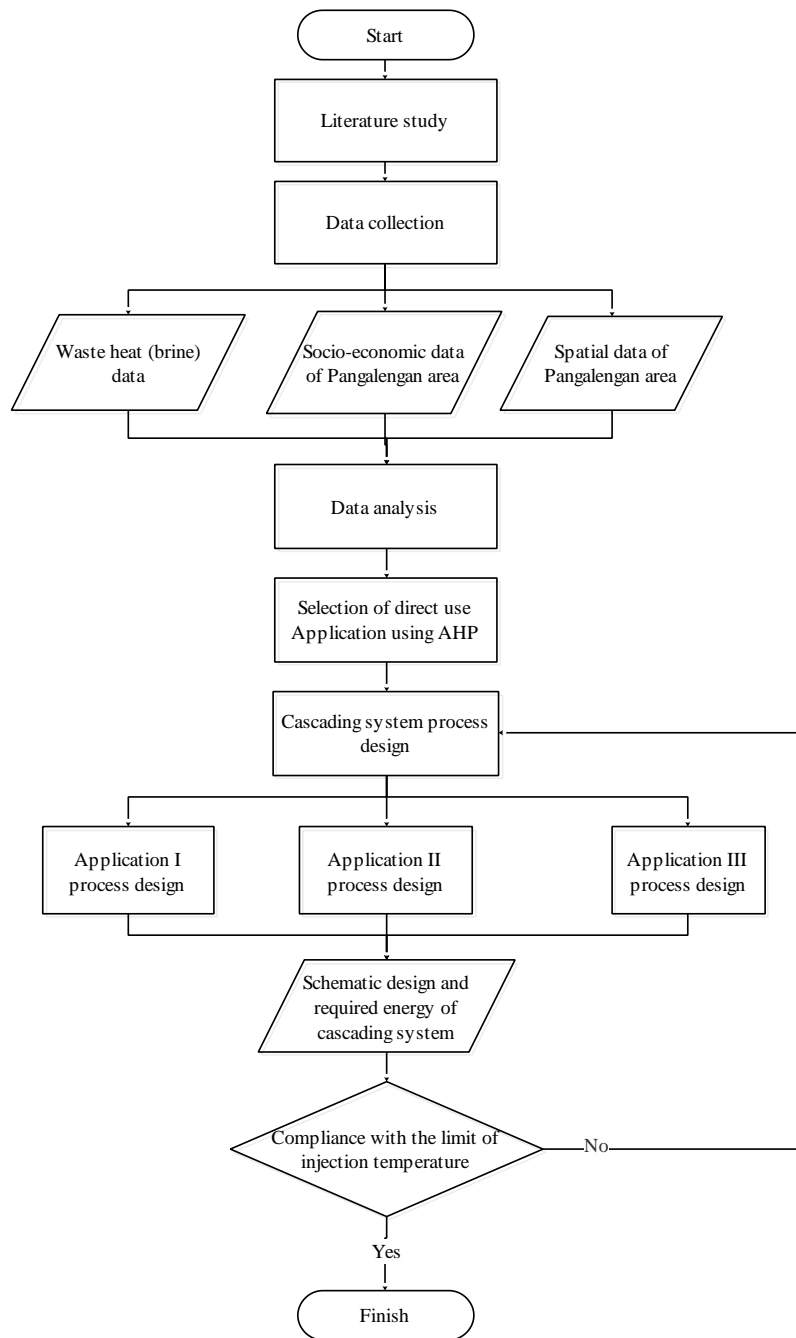


Figure 1: Flowchart of methodology

2.1 Selection of Application

The decision making method to select the application is Analytical Hierarchy Process (AHP). The principle of AHP is simplifies complex problems into simple parts and arrange them in a hierarchy (Saaty 2008). The difference of AHP method compared to other decision making methods lies in the type of input data. The AHP method applies the human perception towards the problems and its consequences based on their experiences. AHP method has more flexibility than other method due to its capability to capture an extensive problems with various criteria, to evaluate quantitative or qualitative input, and also to allow the use of primary data thus avoiding the chance of data availability hurdles.

The method starts by understanding the decomposition of the problem, evaluation of hierarchy and prioritized ranking determination. This decomposition problem or level 1 is selection of prioritized direct use geothermal among the potential commodities. Level two of hierarchy consist of criteria which is contribute the selection. The criteria consist of location of industries, socio-economic condition, technology challenge, and financial aspect. Level 3 and 4 in hierarchy are the breakdown of criteria which known as sub criteria for level 3 and specific sub criteria for level 4.

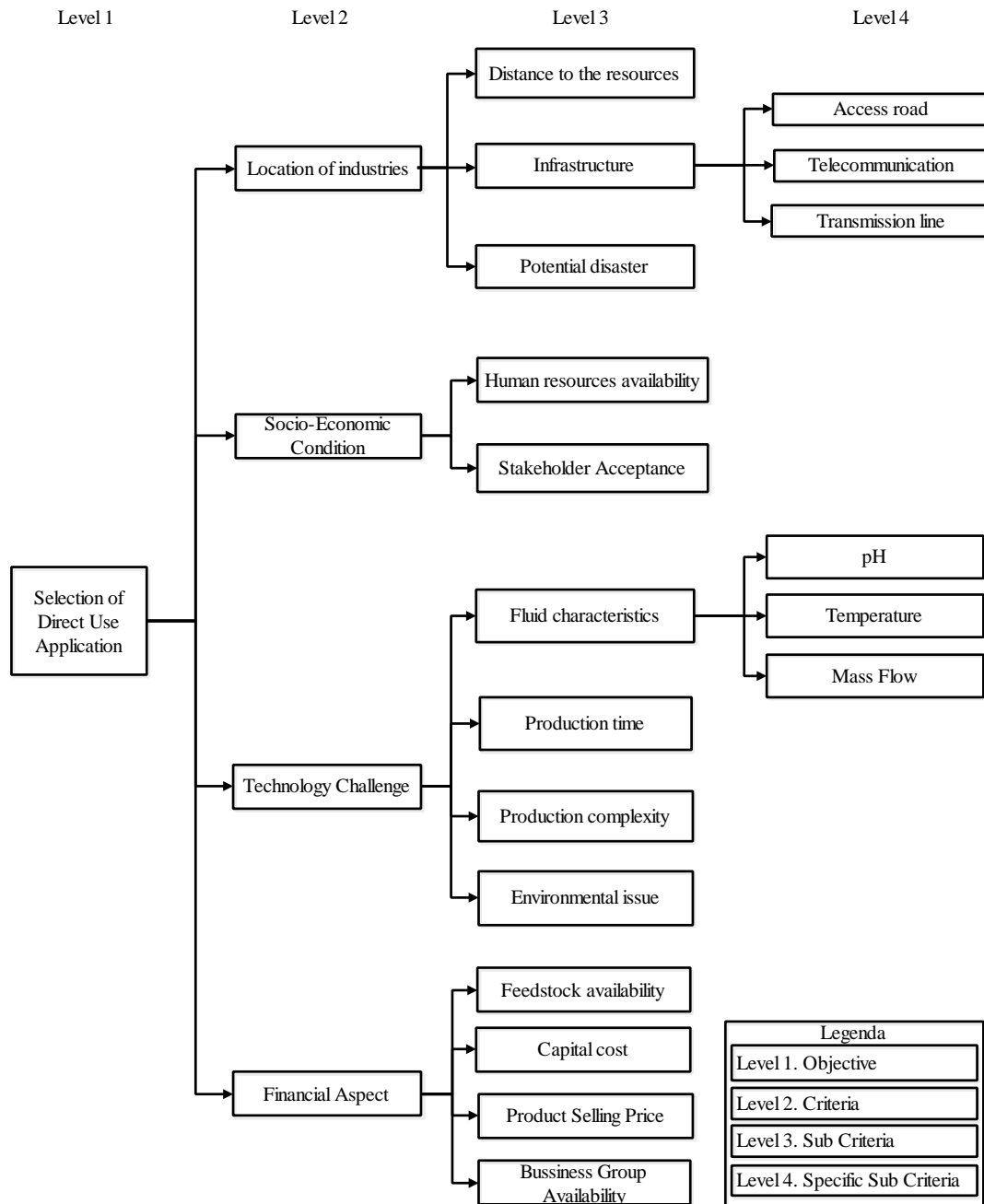


Figure 2: Hierarchy of criteria

The experts who join the AHP questionnaire come from universities, government, and industries. Weight of each criteria, sub criteria and specific sub criteria has been calculated and evaluated with certain conditions. Based on process calculation on over the AHP theory by Saaty 2008, the expert's opinions are formulated and evaluated for each condition pairwise and normalize the calculation. Moreover the consistency of the result will be calculated using consistency index. Table 1 shows result of weighting in AHP which indicates the influential for criteria, sub criteria and specific sub criteria.

Table 1: Results of AHP weighting

Criteria	Weight	Sub Criteria	Weight	Spesifik sub kriteria	Weight
A. Location of industries	0.21	A1. Distance	0.54		
		A2. Infrastructure	0.37	A2.1 Access Road	0.57
				A2.2 Telecommunication	0.24
				A2.3 Transmission line	0.19
A3. Potential Disaster	0.09				
B. Socio-Economic Condition	0.17	B1. Human resources availability	0.30		
		B2. Stakeholder Acceptance	0.70		
C. Technology Challenge	0.42	C1. Fluid characteristics	0.37	C1.1 pH	0.20
				C1.2 Temperature	0.51
				C1.3 Mass low	0.29
		C2. Production time	0.14		
		C3. Production Complexity	0.16		
C4. Environmental issue	0.33				
D. Financial Aspect	0.20	D1. Feedstock availability	0.45		
		D2. Capital cost	0.12		
		D3. Product Selling Price	0.24		
		D4. Bussiness Group Availability	0.19		

Based on Table 1, influential criteria in sequence consists of technologies, location of industries, financial aspects and socio-economic condition. Part of technology criteria, sequentially weight is fluid characteristics, environmental impact, the complexity of the production process, and production time. It was applied to other criteria, the higher the weight, the greater influence in determining the application of direct use. After the weighting process, a calculated AHP was followed by ranking on each of the main commodity areas listed in based on conditions, the scores obtained from each of the potential commodities.

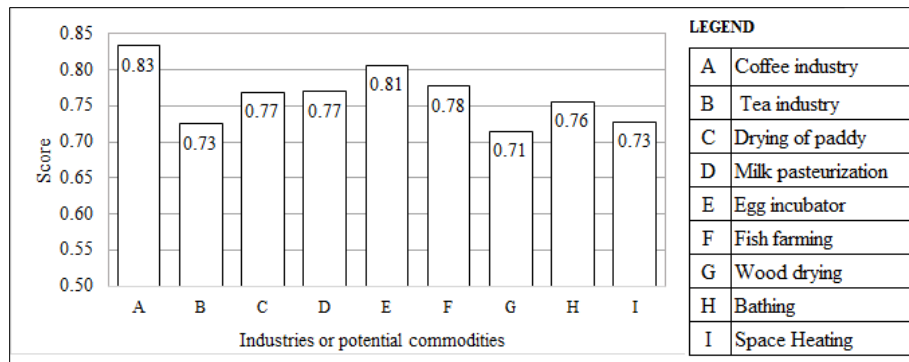


Figure 3: Result of AHP scoring for small to medium industries in Pangalengan

Referring to the socioeconomic data, there are some small and medium industries in the Pangalengan area which use heat energy to process their commodities. Among these are coffee industry, tea industry, paddy drying, milk pasteurization, egg hatching incubator, fish farming or aquaculture, wood drying, bathing and space heating.

The potential commodities at Pangalengan area have a quite high score (above 0.7). It is quite good for every identified small to medium industries. However, to determine the feasibility of direct use implementation, detail calculation and study are required. The application with the highest rank is concluded as the most prioritized application to be implemented. Based on the highest score, the recommended three (3) applications to be designed were coffee drying, eggs hatching incubator, and aquaculture.

2.2 Area Recommendation

By some of considerations, the recommended area of cascading system was located on southern part of Wayang Windu geothermal power plant, which the injection pipeline installed. In addition, the infrastructure conditions and spatial planning regions are also important considerations in determining recommend location. The location is near to existing roads and the river. It also has available transmission line and telecommunication. From the map, distance from central separator to recommended area by following injection pipe is 5.20 km.

2.3 Energy Balance Equation

Energy balance in the cascading system can be calculated using equation 1 and equation 2. While equation 1 is to calculate heat rate is axial direction of the pipe calculate and equation 2 is to calculate heat loss for radial direction of the pipe.

$$q = \dot{m} C_p \Delta t \quad (1)$$

Where \dot{m} is fluid mass flow (kg/s), c_p is specific heat capacity (kJ/kg.K) and ΔT is the temperature difference ($^{\circ}C$).

$$q = \frac{(T_f - T_{\infty})}{R_t} \quad (2)$$

Where T_f is fluids temperature which flow inside the pipe ($^{\circ}C$), T_{∞} is ambient temperature ($^{\circ}C$) and R_t is total resistance for convection and conduction which occurred. From the heat balance in equation 1 and 2, calculated T_{out} fluids in pipe can be expected. For heat exchanger calculation, equation 3 and 4 are used.

$$Q = U_{HE} A_{HE} LMTD \quad (3)$$

Where U_{HE} is heat exchanger coefficient ($W/m^2.K$), A_{HE} is area of heat exchanger (m^2) and LMTD is logarithm of mean temperature difference (K)

$$LMTD = \frac{[(T_{h in} - T_{c out}) - (T_{h out} - T_{c in})]}{\ln \frac{(T_{h in} - T_{c out})}{(T_{h out} - T_{c in})}} \quad (4)$$

Besides the temperature of fluids, pressure is one of important parameter to be calculated in the process design. Pressure drop equation which been used is empiric William- Hazel equation in equation 3.

$$P_{drop} = \frac{4.52 \times \dot{m}^{1.85}}{C^{1.85} \times d^{4.87}} \quad (5)$$

Pressure drop in psi/100 feet of pipe was calculated with \dot{m} refer to quantity rate of flow (gpm), C is roughness coefficient, dimensionless, and d is inside pipe diameter (in). The amount of moisture to be removed in kg (MR) is given in Equation 4.

$$M_R = M \left(\frac{Q_1 - Q_2}{1 - Q_2} \right) \quad (6)$$

where M is amount or capacity of drying per batch (kg), Q_1 is initial moisture content (fraction or %) of the commodities to be dried Q_2 maximum desired final moisture content (fraction or %). Quantity of air required to effect drying (kg). Quantity of air required for effect drying in kg.

$$Q_a = \frac{M_R}{H_{r1} - H_{r2}} \quad (7)$$

Where H_{r1} is initial humidity ratio (kg/kg dry air) and H_{r2} is final humidity ratio (kg/kg dry air). Equation 6 until 9 area the empirical equation to calculate non-covered body of water, exposed to the elements, exchanges heat with the atmosphere (Rafferty 1991) which is the heat loss occurred by 4 mechanism, evaporation, convection, radiation and conduction.

$$q_{ev} = (0.097 + 0.038v) \times (P_w - P_a) \times A \times h \quad (8)$$

$$q_{cv} = (0.198v) \times A \times (T_w - T_a) \quad (9)$$

$$q_{rd} = 0.174 \times 10^{-8} \times 0.93 \times [(460 + T_w)^4 - (460 + T_a)^4] \times A \quad (10)$$

$$q_{cd} = \{[(L + W) \cdot 2] + (L \cdot W \cdot 0.02)\} [T_w - (T_a + 15)] \quad (11)$$

Where v is air velocity (m/s), A is pond surface area (m^2), P_w saturation vapor pressure of the pond water (bara), P_a is saturation pressure at the air dew point (bara), h is heat required to evaporate one kg of water varies in temperature and pressure atmosphere, T_w is water temperature ($^{\circ}C$), T_a is air temperature ($^{\circ}C$), L describe length of pond (m) and W is width of pond (m).

3. RESULT AND ANALYSIS

3.1 Process Design of Cascading System

Process design of cascading system is given in Figure 4. The cascading system divided into four (4) subsystems, which are circulating system, coffee drying, egg hatching incubator and aquaculture. Based on field data in 2014, 82.74 kg/s of brine flowed to the reinjection wells. The amount of brine that is required to be input of the cascading system was calculated iteratively by using Equation (1), (2), and (5). The hot brine from separator transfer the heat to the circulated water in heat exchanger 01 (HE-01). Circulated water is pumped by

Pump-02 from the storage tank (Tank-01) to the HE-01. The heated water from HE-01 is circulated in close loop design. The detail of other subsystems can be found in Subsection 3.2, 3.3, and 3.4.

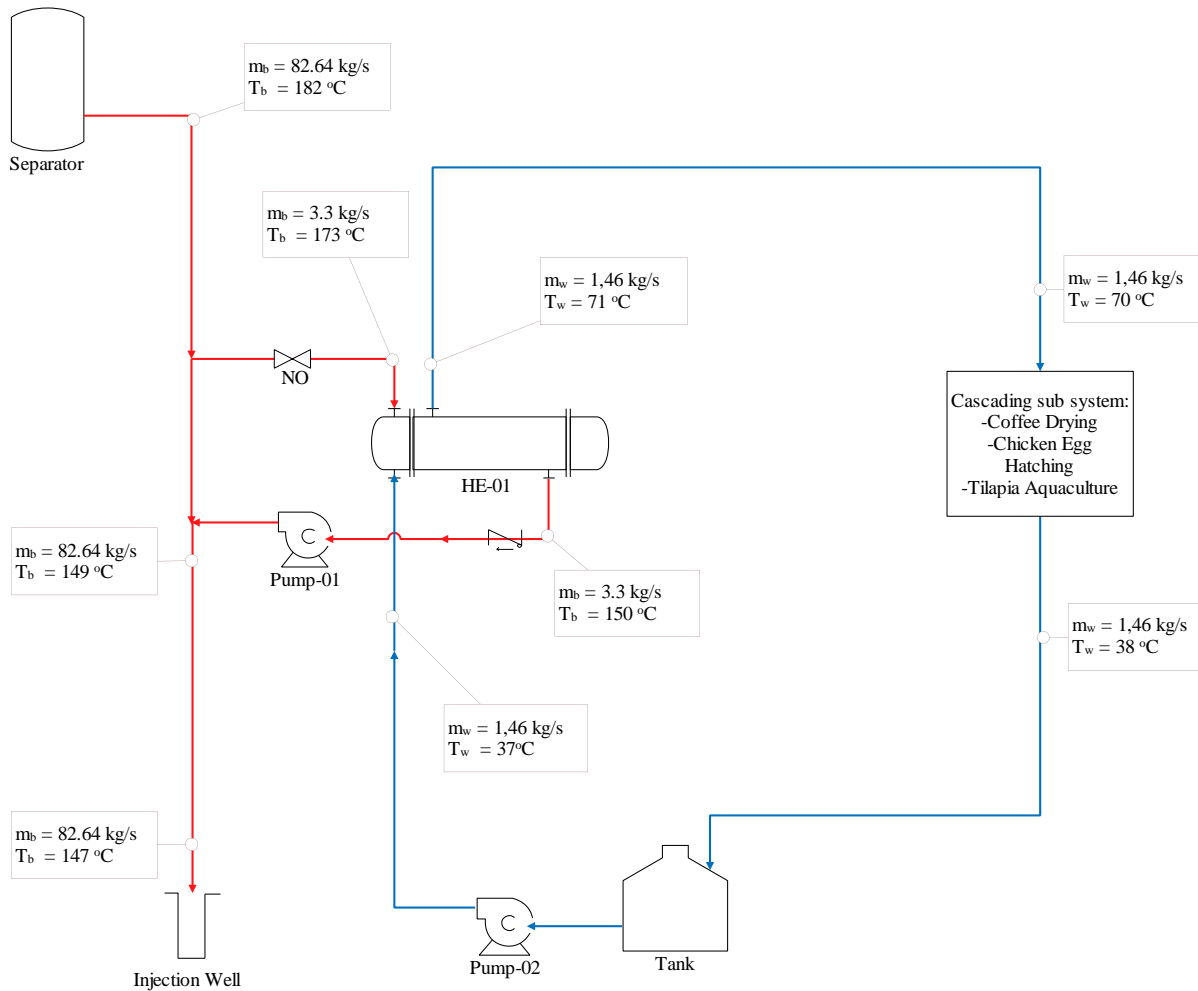


Figure 4: Process design of cascading system

Table 2 gives brief information of brine and circulated water parameter in the circulation system. Table 3 shows the parameter of brine and circulated water pipelines. As per calculation using equation (5), pressure drop for brine line is 0.15 bar/km and 1.54 bar/km for water line.

Table 2: The parameters of fluid in the circulation system

Parameter	Value	Unit
Temperature inlet of brine	182	°C
Temperature outlet of brine	149	°C
Mass flow of brine	3.33	kg/s
Temperature inlet HE-01 of circulated water	53	°C
Temperature outlet HE-01 of circulated water	70	°C
Mass flow of circulated water	1.46	kg/s
Temperature inlet of air	18	°C
Relative humidity air	80	%
Velocity of air	5	m/s
Pressure of air	0.83	bara

Table 3: Parameter of brine and circulated water pipes

Parameter	Value	Unit	Notes
Thermal conductivity of brine pipe	30	W/m.K	Material : Carbon Steel
Diameter of brine pipe for inlet and outlet HE-01	4	in	Iteration or calculation result
Length of brine pipe for inlet HE-01	2.5	m	Calculation result
Length of brine pipe for outlet HE-01	10	m	Calculation result
Thermal conductivity of circulated water pipe	30	W/m.K	Material : Carbon Steel
Diameter of circulated water pipe	2	in	Iteration or calculation result
Length of water pipe for inlet HE-01	10	m	Calculation result
Length of water pipe for outlet HE-01	26	m	Calculation result
Thermal conductivity of insulation	0,05	W/m.K	Material : Calcium Silicate
Thickness of insulation	25	mm	Assumption
Thermal conductivity of jacketing	224	W/m.K	Material : Aluminium
Thickness of jacketing	0,5	mm	Assumption

3.2 Process Design of Coffee Drying

Drying is a process of water removal by using heat and mass transfer. Near Wayang Windu Geothermal Power Plant (GPP), the process of agriculture drying have been done by solar energy or diesel. However, the weather changes and seasonal condition are affecting the drying process. It is leading to cracking, fracturing, and resulting the imperfect drying products. In order to improve the drying process and its result, continuous heat supply is recommend. It can be reached by using continuous energy supply, such as geothermal fluid flows (Sumotarto 2001).

Based on data from the Ministry of Agriculture, the coffee production in the Pangalengan area reached 6499.04 tons in 2014. If the production of coffee per day is assumed steady, the dried coffee products could be reached 17.8 tons/day. In order to simplify the calculation, the assumption of initial volume of coffee bean is 1 ton per batch.

The coffee drying process requires certain duration of time to obtain the desired amount of moisture content. It is determined by these parameters: temperature, drying rate, position and weight of the coffee bean. Based on the mentioned parameters, an efficient design for the drying apparatus is running by 50°C of chamber temperature and 1.7 m/s of air flow rate (Manggala 2011). The assumption of initial moisture content of coffee bean is 50% and final moisture content maximum dry processing by 13% while in the wet processing by 12% (Manggala 2011). Based on earlier studies, the drying machine design was using bed batch which consist of several trays. In order to homogenize drying air condition for each tray, the heat is distributed by blower to drying chamber by channeling system.

The procedure of coffee drying system showed in Figure 5 where circulated water at 70°C of temperature flows from the circulation system after being heated by HE-01. The heated water flows to coffee drying system which is facilitated by the heat exchanger-02 (HE-02) to heat the air inside the drying system. To avoid case hardening, drying must be monitored to maintain 50°C of room temperature. The hardening case is a phenomenon when the outer parts of the products have dried and the inner parts are damp. This phenomenon will increase the water vapor pressure in the product and push the hardened surface so that the surface of the product can be cracked. In addition, the microorganism breeding inside the wet product can defect the product.

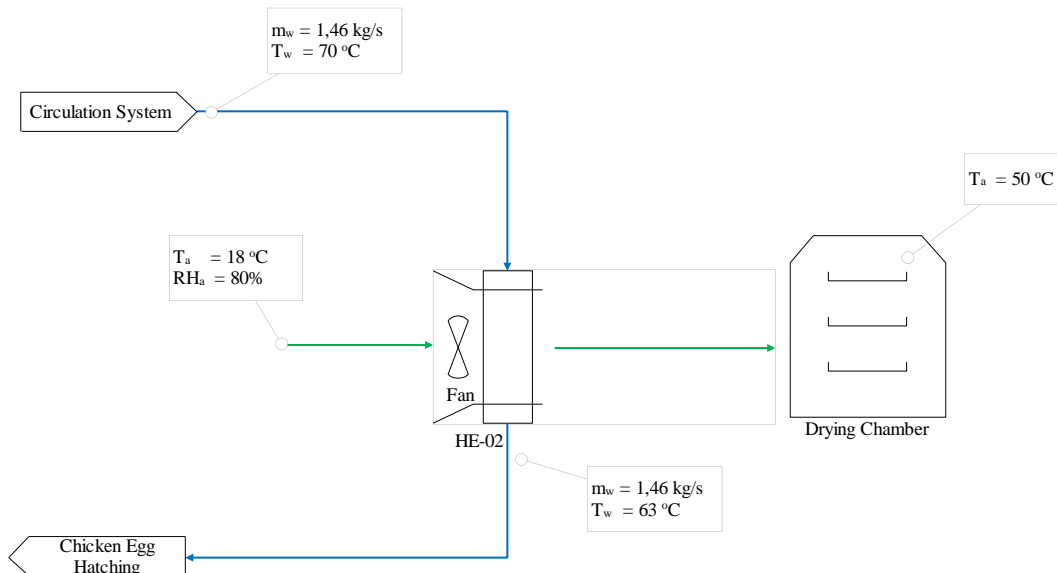


Figure 5: Schematic design of coffee drying

The mass of water that must be removed is calculated by the heat and mass balance equation. Based on calculation, the required energy of coffee drying system is 38.39 kW for 1 ton of coffee which consist of 2.68 kW for heating up and 35.71 kW for evaporating. The summary of calculations related parameters of drying coffee system is presented in Table 4. The hot air from fan in HE-02 transfers the heat energy to the drying system. The detailed parameter in energy balance calculation between hot air and water is given in Table 5.

Table 4: The design parameter of coffee drying

Parameter	Symbol	Unit	Amount
Drying capacity for 1 day	M_c	Kg	1,000
Drying time	t_c	H	8
Relative humidity inlet of coffee	MC_{c-in}	%	50%
Relative humidity outlet of coffee	MC_{c-out}	%	12%
Released of moisture content	MR	Kg	431.82
Released of water mass flow rate	\dot{m}_{mr}	kg/s	0.015
Specific heat capacity of Coffee	C_{p_c}	kJ/kg°C	2.41
Temperature inlet of coffee	T_{c-in}	°C	18
Temperature outlet of coffee	T_{c-out}	°C	50
Heating up coffee	q_{c-hu}	kW	2.68
Evaporation of coffee	q_{c-ev}	kW	35.71
Total heat for coffee drying	q_{c-t}	kW	38.39

Table 5: Energy balance of coffee drying system

Parameter	Symbol	Unit	Air	Circulated Water
Temperature inlet	T_{in}	°C	18	70.0
Temperature outlet	T_{out}	°C	50	63.1
Pressure	P	Bar	0.83	6.53
Density	ρ	kg/m ³	1.09	977.75
Mass flow rate	\dot{m}	kg/s	0.015	1.46
Heat capacity	C_p	kJ/kg°C	-	4.18
Energy	Q	kW	38.39	38.39

3.3 Process Design of Egg Hatching Incubator

Based on a literature review, 50 W_e was used in incubator of 500 hatching eggs. Thus, advance calculation is required to determine the value of heat energy of each egg. Dimension of egg hatching incubator room is 1 m long, 0.7 m wide and 0.5 m high for a capacity of 100-250 eggs (Prihatmaka and Hendrarsakti 2015). It is the basis of the scale up incubator design in this study.

In this study, the proposed egg hatching incubator was designed to hatch 1000 eggs, so that the total power required 100 kW_t. The egg hatching incubator is divided into two rooms to consider the difference of Relative Humidity (RH) condition at the first eighteen (18) days and the next day nineteen (19) until the hatching day. The required temperature and RH of the first room of the first 18 days are 40°C and 55%. Otherwise, the next room for hatching process requires 40°C and 70% of RH. From psychometrics chart, it can be concluded that the humidity ratio for the both inlet rooms is 0.048, the humidity ratio for the first outlet room is 0.032 and for the second room is 0.041.

The hot water temperature of 63°C from the coffee drying system flows to the heat exchanger in the first room. Then, the heat exchanger heats the room up to 40°C by using 35.24 kWh of energy and overall heat transfer rate of 60 W/m². The temperature of hot water at the outlet of the first room is 57°C. The hot water flows into the heat exchange in the second room to heat the room temperature up to 40°C by using the energy of 12.07 kW with overall heat transfer of 60 W/m². The energy transfer decreases the temperature of the hot water at the output of the second room to 55°C. The schematic diagram of the egg hatching system is shown by Figure 6, while the design parameter of the egg hatching incubator and its energy balance are shown by Table 6 and Table 7.

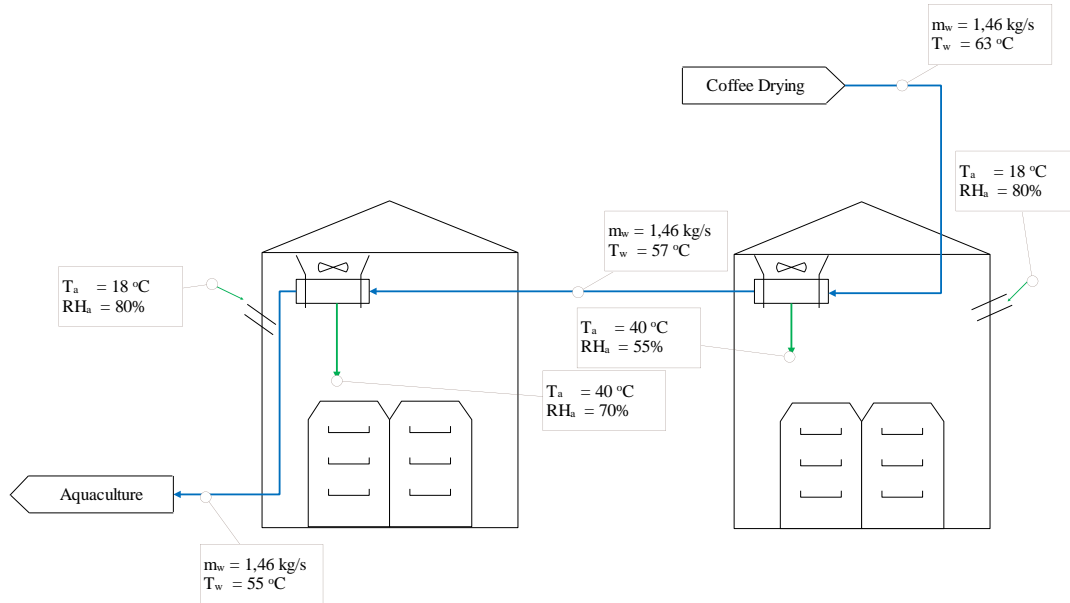


Figure 6: Schematic design of egg hatching system

Table 6: The design parameter of egg hatching incubator

Parameter	Symbol	Unit	Amount
Egg capacity for 1 batch	amount	Egg	1,000
Relative humidity of ambient	RH	%	80%
Relative humidity of room 1	RH	%	55%
Relative humidity of room 2	RH	%	70%
Temperature of room 1	T	°C	40
Temperature of room 2	T	°C	40
Humidity ratio inlet room 1	Hrin ₁	kg/kg	0.048
Humidity ratio inlet room 2	Hrin ₂	kg/kg	0.048
Humidity ratio outlet room 1	Hrout ₁	kg/kg	0.032
Humidity ratio outlet room 2	Hrout ₂	kg/kg	0.041
Total heat for egg hatching room 1	q _{c-t}	kW	35.24
Total heat for egg hatching room 2	q _{c-t}	kW	12.07

Table 7: Energy balance of egg hatching

Parameter	Symbol	Unit	Air	Circulated Water
Temperature inlet room 1	T _{in}	°C	18	63
Temperature inlet room 2	T _{in}	°C	18	57
Temperature outlet room 1	T _{out}	°C	40	57
Temperature outlet room 2	T _{out}	°C	40	55
Pressure	P	bar	0.83	5.1
Pressure	P	bar	0.83	3.7
Density	ρ	kg/m ³	1.09	977.75
Mass flow rate	ṁ	kg/s	0.015	1.46
Heat capacity	C _p	kJ/kg°C	-	4.18
Total energy required room 1		kW	35.24	35.24
Total energy required room 2		kW	12.07	12.07

3.4 Schematic and Process Design of Aquaculture

Tilapia fish is one of West Java's potential commodities which lives in optimum water temperatures of 25-31°C. The production of tilapia fish is not exceeds its target eventhough it is the potential commodity at West Java. Based on observation in Wanayasa, Purwakarta Regency, West Java, the range of size of aquaculture ponds is about 25-1000 m² (Koes 2015). Therefore, the proposed pond area in this research is 200 m² and 1.2 m of depth. This pond capacity is estimated for 400 fish or 1-2 fish/m². The proposed material of

ponds construction is using concrete with heat conductivity value of 0.72 W/m.K. The surrounding rocks temperature is assumed to be constant at 25°C (Koes 2015).

Based on the research Rafferty, 1991, the heat loss that occurs in aquaculture pond is dominated by evaporation, and followed by radiation, conduction and convection. The heat loss calculations based on equation 8-11.

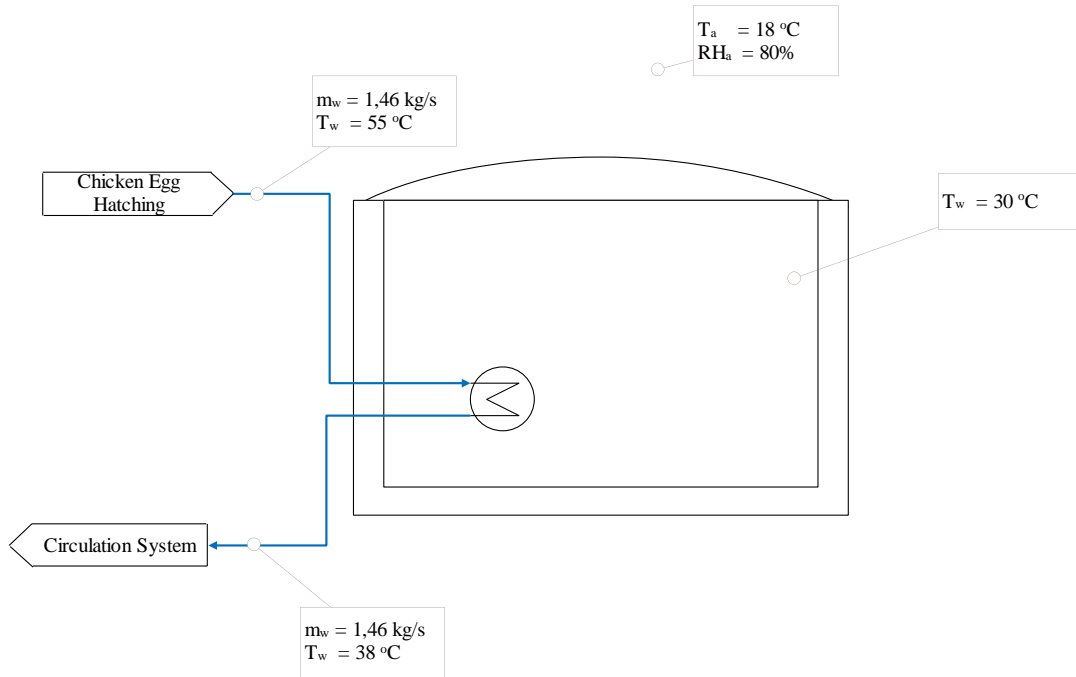


Figure 7: Schematic design of aquaculture pond

The schematic diagram of the egg hatching system is shown by Figure 7, while the design parameter of the egg hatching incubator and its energy balance are shown by Table 8 and Table 9.

Table 8: The design parameter of aquaculture pond

Parameter	Symbol	Unit	Amount
Temperature initial of water	T_{win}	°C	20
Temperature final of water	T_{wout}	°C	30
Length of pond	l_{pond}	m	5
Width of pond	w_{pond}	m	10
Depth of pond	d_{pond}	m	1.2
Heat loss for evaporation	q_{evap}	kW	33.52
Heat loss for radiation	q_{rad}	kW	14.11
Heat loss for conduction	q_{cond}	kW	0.03
Heat loss for convection	q_{conv}	kW	0.0006
Total heat loss	q_{tot}	kW	33.46

Table 9: Energy balance of aquaculture pond

Parameter	Symbol	Unit	Pond water	Circulated Water
Temperature inlet	T_{in}	°C	20	55
Temperature outlet	T_{out}	°C	30	38
Pressure	P	bar	0.83	2.6
Density	ρ	kg/m ³	1.09	994.06
Mass flow rate	\dot{m}	kg/s	-	1.46
Heat capacity	C_p	kJ/kg°C	4.18	4.18
Energy	q	kW	33.46	33.46

4. CONCLUSION

Based on the study, the cascading system using geothermal brine in the Wayang Windu geothermal field is likely to be implemented. However, the acceptance from the operator of geothermal power plant and commodities producers for brine utilization are the important aspect to start the advanced study.

This study concludes several points:

- a. The decision making method using AHP sequentially indicates the influential criteria for direct use prospects consist of technologies, location of the small-medium industries, financial aspects and socio-economic condition.
- b. Based on the social and economic data in the sub district Pangalengan and the calculation results of AHP, the priority of direct use applications are coffee dryings, chicken egg hatching incubator and aquaculture.
- c. The results of heat and mass transfer calculation are:
 - The required heat energy of drying coffee application is 38.39 kW for 1,000 kg of capacity
 - The required heat energy of chicken egg hatching incubator is 47.32 kW for 1,000 of eggs
 - The required heat energy of aquaculture application, especially tilapia fish, is 33.46 kW for 400 tilapia fish
 - The total energy required for cascading system is 119.17 kW
- d. The brine temperature at the exit point of cascading system is 147°C. It indicates the design of the proposed cascading system qualifies minimum temperature of injection.

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