Smart geo-energy village development by using cascade direct use of geothermal energy in Bonjol, West Sumatera

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Abstract. West Sumatera is a province which has a huge geothermal potential - approximately 6% of Indonesia’s total geothermal potential which equals to 1,656 MWe. One of the significant reserves located in Bonjol subdistrict which accounts for more than 50 MWe. The energy from geothermal manifestation in Bonjol can be utilized prior to indirect development. Manifestation at the rate 3 kg/s and 87 °C will flow to cascading system consisting several applications, arranged in order from high to low temperature to efficiently use the excessive energy. The direct use application selected is based on the best potential commodities as well as temperature constraint of heat source. The objective of this paper is to perform a conceptual design for the first cascade direct use of geothermal energy in Indonesia to establish Bonjol Smart Geo-Energy Village which will be transformed as the center of agricultural, stockbreeding, tourism as well as cultural site. A comprehensive research was performed through remote survey area, evaluation featured product, analysis of heat loss and heat exchange in cascade system. From potential commodities, the three applications selected are cocoa drying and egg hatching incubation machine as well as new tourism site called Terapi Panas Bumi. The optimum temperature for cocoa drying is 62°C with the moisture content 7% which consumes 78 kW for one tones cocoa dried. Whereas, egg incubation system consists of two chamber with the same temperature 40°C for each room and relative humidity 55% and 70%. For the last stage, Terapi Panas Bumi works in temperature 40°C. Based on the result technical and economical aspect, it exhibits cascade direct use of geothermal energy is very recommended to develop.

1. Introduction
Indonesia is located along the ring of fire as three tectonic plates collide beneath Sumatera, Java, and Sulawesi. West Sumatera is a province which has a huge geothermal potential - approximately 6% of Indonesia’s total geothermal potential which equals to 1,656 MWe. One of the significant reserves located in Bonjol subdistrict which accounts for more than 50 MWe. The downhole temperature of reservoir near the magma intrusion is estimated to be around 180°C while Sungai Takis as the most potential manifestation to be utilized has 87.9 °C of temperature, 6.9 of pH, 3 kg/s of flow rate, and 243 masl [4].
Geothermal energy can be used both directly and indirectly. Indirect use of geothermal energy typically performed to generate electricity, whereas direct uses are addressed to help industrial process such as heating, drying, sterilization and/or pasteurization. Absorbing all the possible of heat from the hot fluid and utilize it as efficient as possible brings out a method termed “Cascade System” used in several stages as for maximizing heat utilization of the working fluid from the previous stage to the next stage. The stages are divided by considering the temperature required which the highest temperature is put at the first stage.

Thus far, many agro industries still use large amount of diesel or even conventional sun drying method as a source to generate thermal energy for conducting those processes. Diesel may be a flexible fuel, nevertheless, high consumption of it can contribute to global warming due to high carbon dioxide emission while sun drying method relies on weather conditions which lead to concern on drying time especially on rainy season which could result in longer time to dry. Even in dry season, it may last seven days to meet specification of water content due to sunlight fluctuation where the longer duration of drying using this method may cause possible damage of cocoa beans due to mold development [5]. The industries usually hatch eggs using bulb as the heat source that can lead to several problems. For instance, unequally distributed egg’s temperature requires it to be properly treated inside continuously.

Cocoa drying can be a big potential revenue for the region because it will enhance the price of the cocoa commodity. But if using conventional drying method, weather fluctuation can impact the quality of cocoa commodity product which will reduce the farmer’s profit. Incubation method for egg’s hatching used in Bonjol uses electricity to provide heat. However, every year it is estimated to 115 MWh electricity spent by this method. Due to high price of electricity, high use of it can be a source of economic potential loss for egg hatching business. Tourism and cultural potential in Bonjol has not been fully exploited yet. It only depends on the visitors who visit the Museum.

The objective of this paper is to perform a conceptual design for the first cascade direct use of geothermal energy in Indonesia to establish Bonjol Smart Geo-energy Village. Bonjol Smart Geo-energy Village is a village located in Bonjol which directly utilize a geothermal energy for several needs. Bonjol Smart Geo-energy Village will be transformed as the center of agricultural, stockbreeding, tourism as well as cultural site to increase the welfare of local community.

Direct use of geothermal energy is normally developed in unintegrated manner. It means the utilization is only aimed at a specific process where the waste heat usually unused. But, in this paper, author will develop Bonjol through cascade direct use of geothermal energy to form a “Smart Geo-Energy Village” which means no heat will be wasted.

2. Geothermal Potential in Bonjol

Bonjol geothermal area is located at Bonjol subdistrict, Pasaman regency in the Province of West Sumatera. Geothermal manifestations consist of neutral pH hot springs with temperature ranging from 49.7 °C to 87.9 °C. Geothermal manifestations spread over in center of Bonjol area are predominated by appearance of hot springs in Padang Baru, Takis river, Limau river, and Kambahan river. Hot springs with the highest temperature are located at Limau river, Takis, and Kambahan, which is located in Sumatera depression zone and controlled by Takis fault. Takis hot spring has temperature about ± 87.9 °C and pH 6.9. Limau river hot spring has temperature about ± 73.5 °C, pH 7.3. Kambahan hot spring has temperature about 73.4 °C, pH 7.5 [8].

The geothermal reservoir fluid is chloride type, indicating hot water dominated reservoir. Geothermal system in this area is supposed to be associated to volcanic activities. The youngest volcanic is Binuang dome which is supposed as a heat source for the geothermal system of the area. Gravity data reveal a high anomaly which is interpreted as an intrusive body beneath Takis hot spring. [8] Heat source potential is estimated ± 3000 m depth as andesitic igneous intrusion that resulted from eruption of Bukit Gajah in quaternary period. The reservoir temperature in the Bonjol area is estimated about 180 °C from water geothermometry and had moderate enthalpy. Heat loss factor at
Bonjol area reach up to 1 MWe and the geothermal potential is predicted can produce energy ± 50 MWe [3].

3. Cascade Definition and Characteristics

Cascade utilization of geothermal energy is a reasonable sequential arrangement to use energy at different thermal levels and to obtain several products such as drying fish, balneology, aquaculture, green house, etc. Cascade utilization of geothermal resources allows to obtain multiple products from a single resource or coupling to other renewable sources, thus having a better utilization and energy saving, and avoiding an excess consumption of unrenewable resources.

There are several possibilities to utilize geothermal energy in cascade manner, but in general, it is possible to identify two main groups: cascade systems with electricity production and thermal uses, and cascade systems comprising only thermal uses. Cascade systems with electricity production are suitable when geothermal resource has temperatures greater than 90 °C, with more opportunity of integrate various thermal levels as temperature increases. Cascade systems with only thermal uses are appropriate for geothermal resources with temperatures below 90 °C.

The cascade system for geothermal energy has been developed around the world, such as America, Europe, Africa, Asia, and other regions. In Africa, direct use applications are highlighted for shallow wells, focusing on drying of agricultural products and food. The temperature range suitable for cascading direct uses is 89 °C in wellhead and an outlet temperature for the last level of the cascade of 50 °C [7]. In Indonesia, until now there is no application of cascade system utilization for direct use. If this project can be implemented, it will be the first ever cascade utilization for direct use in Indonesia.

![Lindal Diagram](image)

**Figure 1. Lindal Diagram**
Cascade direct use is inspired by Lindal diagram (see figure 1) which is a brief of potential direct application of geothermal energy based on the range of working temperature is proposed by an engineer named Baldur Lindal. It delivers insight concerning how to improve direct use geothermal energy efficiency by introducing a wide combination of usage

4. Methodology

4.1. Workflow
The research consists of planning stage, literature study, remote survey area, evaluation and analysis of featured product, analysis of heat loss and heat exchange in cascade system, plan of development and study compilation respectively.

In planning stage, authors determine research limitation, the objective, problem identification and research workflow. After that, literature study is done to address the direct utilization of geothermal energy which have succeeded to be developed in either pilot or commercial scale. It also includes geothermal potential evaluation study in Bonjol, agricultural production data, and other featured product. Information regarding potential is obtained through Pusat Sumber Daya Geologi (PSDG) as the assessor of Bonjol geothermal appointed by Indonesia. Featured regional product data is obtained through government official website and papers.

The next step is remote survey area. The survey is conducted to understand the real condition of the field including resources distance to the nearest social community, accessibility and topography of region. Due to limited time and resource, area survey is conducted remotely through satellite information provided by google earth and street view feature.

After all the required data is collected, authors conduct evaluation and data analysis which integrate the literature and survey data to form an evaluation in the perspective of technical, social and economic aspect. After evaluation and data analysis has been set up, Plan of Development is designed in the use of cascade direct use system. And eventually, all result study is compiled.

4.2. Thermodynamics Principle and Transportation of Heat

4.2.1. Pipeline
The principle of heat transfer in the flowing fluid in pipe is based on conduction and convection process. This phenomenon can be illustrated by figure 2.

In order to evaluate the heat loss along the pipeline, there are three major process should be taken into account : 1). Convection process inside the pipe, 2). Conduction process within the pipe and insulator ,and 3). Convection process from outer wall of pipe to the surrounding area. The heat transfer resistance (R) as the obstruction of driving force are evaluated through these formula:

\[ Q = \frac{T_{\text{water}} - T_{\text{air}}}{R_i + R_a + R_b + R_c} \]  

Figure 2. Heat transfer in pipe
4.2.2. Heat Exchanger

By applying the principle of heat transfer in thermodynamics and fluid dynamics in one shell pass and one tube pass in counter-current flow heat exchanger, the temperature outlet of both heat source and cold source in heat exchanger could be determined as below.

\[ Q = m \times C \times T \]  
\[ Q = U_{he} \times A_{he} \times LMTD \]  

Thus, LMTD can be evaluated below.

\[ LMTD = \frac{[(T_{in,1} - T_{out,1}) - (T_{out,2} - T_{in,2})]}{\ln \frac{T_{in,1} - T_{out,1}}{T_{out,2} - T_{in,2}}} \]

Calculating water mass contained in cacao which need to be evaporated

\[ M_R = M \times \frac{Q_1 - Q_2}{1 - \theta_2} \]  

Calculating air rate required to reduce water content from initial humidity to final humidity before entering the drying room.

\[ Q_a = \frac{M_R}{t} \]

The nomenclature for those all symbol is presented in Appendix A.

5. Result

5.1. The Prospect of Direct Utilization of Geothermal Potensial in Bonjol

Based on the literature, the geothermal potential in Bonjol is expected to be over 50 MWe where the manifestations spread over in center of Bonjol. The area is predominated by appearance of hot springs in Padang Baru, Takis river, Limau river, and Kambahan river which the highest temperature are located at Limau river, Takis, and Kambahan in Sumatera depression zone. Heat source potential estimation yields ± 3,000 m for the depth as andesitic igneous intrusion, and the temperature of reservoir is 180 °C which can be used to generate electricity and directly use it. Due to indirect utilization can’t be realized in the near future, the manifestation heat can be utilized as the heat source of the cascade direct use geothermal energy system.

However, considering the distance, accessibility, and temperature to the three of these manifestations, the authors decided Takis river hot spring which has temperature about 87.9 °C as the manifestation source. Takis River hot spring is located at a distance of about 1.6 km from the nearest village and has a 243 m elevation. This position is very suitable as a source for the cascade system to be developed because it does not require a pump but it just need pipeline to flow the water from the Takis river to Smart Geo-Energy Village.

Based on literatures, Cascade systems with only thermal uses are appropriate for geothermal resources with temperatures below 90 °C. Due to low manifestation temperature which is 87.9 °C, Takis river as the heat source of cascade system can’t be used for electricity but it only can uses for thermal uses specifically in direct use. Based on Lindal diagram, this temperature can be direct use for drying fish, refrigeration, green house, balneology, aquaculture, bi-degradation fermentation, agriculture, etc. In Indonesia, until now there is no application of cascade system utilization for direct use. If this project can be implemented, it will be the first ever cascade utilization for direct use in Indonesia.

The cascade system to be developed consists of three levels, those are cocoa beans drying machine, chicken egg incubation, and Terapi Panas Bumi. The selection of this levels is based on the
study of agricultural commodity, livestock commodity and tourism sites in Bonjol. In agricultural, Pasaman regency agricultural potential are massively focus on cocoa beans and chicken egg commodity. In 2014, the production of cocoa beans in Pasaman regency is 14,409 ton with selling price Rp 3,000/kg (Bank Data Dinas Pertanian Nasional, 2014). Prospectively, this commodity is probable to be developed. In other hand, Bonjol as a subdistrict in West Sumatera is acknowledged in 2007 to be one of an agricultural region plan. Of course, this project is so profitable to be developed.

In livestock commodity, as shown in Sumatera Barat livestock report by 2014, the production of chicken eggs in Pasaman is 115 ton. The incubation process for chicken eggs goes hand in hand with cocoa drying process which is still using conventional drying method with lamp as the energy source which approximately consumes 9.3 MWh to hatch one tenth of the produced eggs. In this study, the authors’ aim is to make a projection that Bonjol as the central drying cocoa beans and chicken egg incubation in Pasaman. By making Bonjol as a center of drying cocoa beans and chicken egg incubation industry as described previously, this project would open up employment opportunities for the community in Bonjol and nearby region.

Astonishingly, tourism potential has not been fully exploited yet showed by the published tourism site merely Museum of Tuanku Imam Bonjol (Web Kabupaten Pasaman, 2014). Pasaman regency known as the area which is passed through by the equatorial line, particularly in Bonjol, may take opportunity for tourism sector to be developed. In this study, the authors wanted to attract attention in the tourism sector by making a Terapi Panas Bumi in Bonjol. If this project successful, this will makes a first ever a massage based on geothermal energy in Pasaman regency.

![Figure 3. Location of Smart Geo-Energy village (Google Earth Maps)](image-url)
5.2. Recommendation Location for Direct Use Utilization

In determining the recommended location, the consideration are the manifestation distance, accessibility, tourists travel opportunities, and population residents. The chosen location is as shown in Figure 3. The location is a village so that it can be used as Smart Geo-Energy Village. The distance of Takis River manifestation to the location is approximately 1.6 km to the economic considerations which will be the further project of this paper.

This village is the nearest village to the Takis River hot spring, so economically this village is the most suitable location to be developed. From Figure 3, the length of pipeline needed is about 1.6 km. These locations can be accessed from the Jalan Lintas Sumatera with a distance about 500 m. This location is deemed lucrative to attract travelers because the pathway to this location is in front of the equator monument and Tuanku Imam Bonjol museum which is a crowded tourist spot. Another reason, why tourism will attracted to this village because Bonjol has so many cultural art, such as Randai, Rabab and Lukah gilo which is usually performed in traditional event, culminative point event, and international annual event (Tour de Singkarak).

5.3. Cascade System Design for Direct Use

The geothermal manifestation in Bonjol can’t be used to generate electricity. However, based on Lindal diagram and availability of featured product in Bonjol, the geothermal manifestation will be used for direct utilization by applying cascade system. Cascade system consisting several application, arranged in order from high to low temperature to efficiently use the excessive energy, is designed like in figure 4.

5.3.1. Design for Drying Cocoa Beans

Hot water flows from the takis river hot spring manifestations through the cocoa beans drying system at 71.4 °C and will pass through a heat exchanger. After passing through the heat exchanger, the air will be blown towards the drying chamber with the arrangement tray containing cocoa seeds. The schematic design of cocoa drying machine is shown in figure 5. The performance of cocoa drying system is presented by table 1. Based on the calculation of mass and heat transfer that has been done, obtained the working parameter that can be summarized in table 2.

To avoid case hardening (the outside of the dried seeds while the inside is still moist), the temperature during the drying process should be maintained at 62 °C. The conclusion of the calculated parameters related to cocoa drying is presented in table 2.

Figure 4. Scheme of cascade direct use system of geothermal energy in Bonjol
Figure 5. Schematic design of cocoa drying machine

Table 1. Work performance of drying cocoa beans.

| Parameters                              | Value | Units |
|-----------------------------------------|-------|-------|
| Capacity of drying cocoa per day        | 1000,00 | Kg    |
| WC initial                              | 0,80  |       |
| WC final                                | 0,07  |       |
| HR 1                                    | 0,75  |       |
| HR 2                                    | 0,40  |       |
| Drying time                             | 7,00  | Hours |
| M water contained                       | 783,92| Kg    |
| M of air needed                         | 0,09  | kg / s|
| Specific Heat Capacity of cocoa         | 3,10  | kJ/kg |
| Tcocoa inlet                            | 28,60 | °C    |
| Tcocoa outlet                           | 62,00 | °C    |
| Power for heating-up                    | 4,11  | kW    |
| Latent heat of evaporation              | 74,09 | kW    |
| Total Power                             | 78,20 | kW    |


Table 2. Work parameters of drying cocoa machine.

| Parameters     | Air     | Water   | Units |
|----------------|---------|---------|-------|
| Tin            | 28,60   | 71,40   | °C    |
| Tout           | 62,00   | 65,16   | °C    |
| Pressure       | 0,98    | 1,00    | Bar   |
| Density        | 1,09    | 977,75  | kg/m³ |
| Flow rate      | 0,09    | 3,00    | m³/s  |
| Heat capacity  |         | 4,18    | kJ/kg °C |
| Energy         | 78,20   | 78,20   | kW    |
| Velocity       | 0,74    | 0,77    | m/s   |
| Cross-section area | 0,11   | 0,00    | m²    |

5.3.2. Design for chicken’s egg incubation system

Temperature, humidity, and ventilation are three important parameters to successfully hatch the eggs. The eggs need to be kept at 40°C at all times and incapability to sustain this condition will eventually terminate the embryo. Humidity should be maintained to 40-60% in the first 18 days and 65-75% for the final days before hatching. And ventilation will allow oxygen to enter because the fetuses need fresh air to breathe.

In this scenario, geothermal energy will provide heat energy to maintain the temperature. By using cascade system, the hot water from cocoa drier will be used again to flow in this system.

Figure 6. Schematic design of egg incubation machine.
5.3.3. Design for "Terapi Panas Bumi"

The temperature for Terapi Panas Bumi is expected to be 40 °C. The hot water from incubator will flow to pool and accumulate. After that hot water will be flown to river near the location. Due to, no harmful chemical solution, directly flowing to the water is justified. The Schematic design of Terapi Panas Bumi is shown in figure 7.

6. Conclusion

The heat transfer calculation shows that it is possible to maintain the required temperature for every stage. Therefore, early development of geothermal energy in Bonjol is encouraged to be established through Cascade system with three stage of uses: Cocoa bean drier, egg hatcher, and tourism potential.

However, further economic studies is required to show whether it is worth it. Hypothetically, the development of Smart Geo-Energy Village should boost the economy of Bonjol and Pasaman District through multiplier effect as well. Firstly, the tourism project will boost the micro businesses in food court, transportation services and others because the expected growth of tourist. Secondly, Bonjol could grow into specialized commodity processing sector because of high quality and low price of drying coupled with the availability of electricity supply in the future. Thirdly, these growths will eventually provide more job opportunity for local people.

7. Further Research Project

The further research project of this paper is:
1. Drier design to calculate volume required to meet the expected drying condition to prevent spoilage of the cocoa.
2. Heat exchanger design.
3. Community acceptance of the project.
4. Cascade system with electricity as well.
5. Project Economic Study.

The objective of economic analysis which we shall explore is to find whether the project is profitable both for investor and community around. We will start by evaluating the cost and revenue stream and the move into net present value as, pay out time and profitability index of the project.
The further project will evaluate cost of development from two source of manifestation and seek for the best scenario and compare it to current method of drying cocoa and hatching egg. After that, author will analyze profitability of Terapi Panas Bumi tourism in terms of Net Present Value, Profitability Index, and Internal Rate of Return.

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APPENDIX A

Properties, symbol and unit

\( \mu \) = Dynamic viscosity (kg/m s)
\( A_{\text{alm}} \) = Log mean areas for pipe
\( A_{\text{blm}} \) = Log mean areas for insulator
\( A_{\text{hec}} \) = Heat transfer area (m²)
\( A_i \) = Surface area of inner pipe
\( A_o \) = Surface area of outer insulator
\( C \) = Specific heat capacity of heated fluid (kJ/kg K)
\( D \) = Diameter of pipe contacted by fluid (m)
\( h_i \) = Convective coefficient of water
\( h_o \) = Convective coefficient of air
\( Hr_1 \) = Humidity ratio before contact with cocoa
\( Hr_2 \) = Humidity ratio after contact with cocoa
\( k_a \) = Mean thermal conductivity of pipe
\( k_b \) = Mean thermal conductivity of insulator
\( \text{LMTD} \) = Log mean temperature difference (K)
\( m \) = Flow rate of fluid (kg/s)
\( m \) = Flow rate of heated fluid (kg/s)
\( M \) = Mass of cocoa bean
\( M_R \) = Mass of water content in cocoa to be evaporated
\( Q \) = Heat calculated (kW)
\( Q_1 \) = Final water content
\( Q_2 \) = Initial water content
\( Q_a \) = Mass of air needed in cocoa drying
\( r_o \) = Radius of outer insulator
\( T \) = Temperature of heated fluid (°C)
\( T_{\text{air}} \) = Ambient temperature
\( T_{\text{C in}} \) = Cold water inlet temperature (°C)
\( T_{\text{C out}} \) = Cold water outlet temperature (°C)
\( T_{\text{H in}} \) = Hot water inlet temperature (°C)
\( T_{\text{H out}} \) = Hot water outlet temperature (°C)
\( T_{\text{water}} \) = Temperature of water
\( U_{\text{hec}} \) = Heat transfer coefficient HE (W/m² K)
APPENDIX B

Temperature of Fluid Calculation in Each Level of Cascade System

Table 3. Temperature of fluid in each level of cascade system

| Level                      | Fluid      | Temperature (°C) |
|----------------------------|------------|------------------|
| Flowing in Pipe            | Water      | 87.9             |
|                            |            | 71.4             |
| HE-1 in Drying Cocoa Beans | Water      | 71.4             |
|                            |            | 65               |
| HE-2 in Hatching Eggs      | Water      | 65               |
|                            |            | 55               |
| Mixing Water Before Pool   | Water      | 55               |
|                            |            | 40               |
| Pool                       | Water      | 40               |
|                            |            | 28               |

Figure 8. Distribution of temperature of water along the pipeline in cascade system

Where,
1 represents water flow in pipe
2 represents heat exchanger 1 in drying cocoa beans
3 represents heat exchanger 2 in hatching eggs
4 represents hot spring & spa in pool
APPENDIX C

The interface of Macro Excel Program to Calculate Heat Loss in Fluid Flow in Pipe

![Image of the interface of Macro Excel Program to Calculate Heat Loss in Fluid Flow in Pipe]

- Heat loss rate of a pipe in an outdoor location
- Note 1: Saturated steam or Saturated water
- If the fluid is a "saturated steam" or "saturated water", there is no need to input any value in the cells of "q_{Preheat}" and "q_{Preheating}", corresponding to the case of "superheated steam or subcooled water". Any value in these cells will not be considered.
- Note 2: Superheated steam or subcooled water
- If the fluid is a "superheated steam or subcooled water", there is no need to input any value in the cell of "q_{Preheat}" corresponding to the case of "saturated steam" or "saturated water". Any value in this cell will not be considered.

### Input data
- 1. Pipe nominal diameter \( d_p = 4 \text{ in} \)
- 2. Pipe schedule \( Sch = 40 \text{ -} \)
- 3. Pipe length \( L_p = 2600 \text{ ft} \)
- 4. Pipe absolute roughness \( R_a = 0.01 \text{ mm} \)
- 5. Insulation material \( Ins = \) Mineral Fiber Pipe, 1555 Type 851, 23.8°C to 253.1°C

### Results
- Results using the array function: Module: Outdoor_Pipe_heat_loss_array
  - \( U = 0.003 \text{ W/mK} \) (Combined convection and conduction coefficient for a horizontal surface)
  - \( h_{int} = 29.5 \text{ W/mK} \) (Combined radiation and convection coefficient for a horizontal surface)
  - \( h_{pipe} = 3.0 \text{ W/mK} \) (Average pipe temperature)
  - \( k_{int} = 0.0596 \text{ W/mK} \) (Average insulation temperature)
  - \( t_l = 120.25 \text{ °C} \) (Temperature of pipe interior surface)
  - \( t_s = 30.13 \text{ °C} \) (Temperature of insulation exterior surface)
  - \( U_g = 3.158 \text{ W/mK} \) (Global heat transfer coefficient reduced to the exterior surface)

- \( Q = 207.505 \text{ W} \) (Heat loss for the pipe of length 1')

- Result using the single function: Module: Outdoor_Pipe_heat_loss_Q
  - \( Q = \text{HeatLossOutdoorPipe}(\text{Sch}, L_p, R_{a, int}, \text{insulation thickness}, \text{Ins}, \text{fluid}, R_{a, pipe}, p_{\text{in}}, p_{\text{out}}, U_{\text{f, int}}, h_{\text{int}}, h_{\text{pipe}}, U_g, A_{\text{int}}, f_{\text{int}}, v_{\text{pipe}}, K_{\text{int}}) \)
  - \( Q = 207.505 \text{ W} \)