

# Organic Rankine Cycle Analysis on Geothermal Based Electric Power Plant in Tulehu Village, Maluku

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## ABSTRACT

The rapid development of technology has an impact on the increasing human need for energy, especially electricity. At present, population growth and climate change are encouraging new interest and investment in renewable energy sources to provide access to reliable and sustainable energy. One of the renewable energy sources with huge potential in Indonesia is geothermal. With the advancement of geothermal technology, low-temperature sources can be used as a source of electrical energy by using an organic Rankine cycle (ORC). The use of low-temperature geothermal sources can be an electrical energy solution for areas in Indonesia that are located still far from cheap electricity generation. In this research, a geothermal ORC plant study was conducted with a research location in Tulehu, Maluku. The source used is the TLU-01 exploration well with its geothermal fluid characteristics, namely 3 bar pressure, temperature 133.5 ° C, and debit of 238.89 kg / s. The results of this study are the use of a preheater and recuperator can increase the efficiency of the plant, with the highest efficiency obtained is 12.6% and the power generated is around 1800 kW. The highest efficiency plant design uses the R245FA work fluid with a maximum temperature of 133.5 ° C, a maximum pressure of 9 bar, a minimum pressure of 1.85 bar, and a mass flow rate of the working fluid of 65.5 kg / s. The cost of generation using the system is Rp. 1093.94, or 64% lower than the BPP of Ambon city in Maluku.

**Keywords:** ORC, Geothermal, Renewables, Indonesia, Energy

## 1. INTRODUCTION

One of the renewable energy sources with huge potential in Indonesia is geothermal energy. High-temperature geothermal sources are commonly used as an energy source for electricity generation. Meanwhile, low-temperature geothermal sources are used in direct applications. However, with advances in geothermal technology, low-temperature sources can be used as a source of electrical energy by using organic Rankine cycles (ORC).

The utilization of low-temperature geothermal sources in Indonesia is still very small. Of the 13 existing PLTPs, only one PLTP uses a low-temperature system. In this research, a geothermal ORC plant study was conducted with a research location in Tulehu, Maluku using Epsilon Professional and Thermolib. The source used is the TLU-01 exploration well with its geothermal fluid characteristics, namely 3 bar pressure, temperature 133.5 ° C, and debit of 238.89 kg / s.

### 1.1. Related Work

Geothermal energy is renewable energy. The use of geothermal energy has been carried out by human civilization since ancient times, for example in the Pompeii civilization, which used geothermal as a source of hot springs to warm their homes [1].

Based on the temperature of the working fluid, geothermal sources are divided into two, namely high temperature ( $T > 150$  ° C) and low-medium temperature ( $T < 150$  ° C) [2]. High-temperature geothermal sources are commonly used for electricity generation while low-temperature geothermal sources are commonly used for direct use, for example for heating systems of one area or large structures such as factories [3]. However, with advances in geothermal technology, low-temperature geothermal sources can be used as a source of electrical energy. This can answer the problem of high-temperature geothermal sources, namely their difficult exploration and less abundant sources which cause expensive development and exploration costs, compared to low-temperature geothermal sources. At low-

temperature geothermal plants, binary cycles such as organic Rankine cycles or ORC are used.

Geothermal plants with binary cycles that use low-temperatures can be a solution to environmental problems because with this system we can reduce greenhouse gas emissions and the consumption of non-renewable energy sources [4].

Binary cycle plants use ORC to extract heat from low temperature geothermal fluids (water or steam). Binary plants are usually more complex than traditional types because the geothermal fluid has to pass through a heat exchanger which also heats up other working fluids. In this cycle, other working fluids used have a lower boiling point than water, namely refrigerants or hydrocarbons [5]. Its function is to rotate the turbine after evaporating, then cool it with water [6].

ORC systems can be part of electrification in remote areas. This technology opens a new market in the world of the electricity industry and offers solutions to increase the use of renewable energy. There are still some challenges that still have to be faced in the development of the ORC system, including the selection of a good working fluid, low efficiency, and unknown environmental impacts [7].

The manufacturing cost of an ORC generator depends on the type of application. The factors that affect the cost are size, location, land price, heat source temperature level, the nature of the heat carrier, water availability, labor, materials, capital costs, storage systems, and backup systems. As for the ORC technology itself, the price is very much influenced by the type of turbine and the working fluid used [7].

### 1.2. Our Contribution

The scientific benefits of this paper are as follows:

1. Support the use of new and renewable energy in order to meet the energy mix target in 2025.
2. Help resolve the issue of electricity generation in the Maluku area.
3. Provide references on the use of low temperature geothermal as a source of electrical energy in Indonesia.

### 1.3. Paper Structure

The rest of the paper is organized as follows. Section 2 introduces the preliminaries used in this paper, which include the ORC system and the Geothermal ORC system. Section 3 presents the methodology used in the research. Then, in section 4, we presented the results and analysis from the research. Finally, section 5 concludes the paper.

## 2. BACKGROUND

### 2.1. Organic Rankine Cycle

Organic Rankine Cycle (ORC) is a modification of the Rankine cycle which usually uses high pressure and high-temperature water as a working fluid while ORC uses a working fluid with a lower boiling point, so water is not suitable for use as a working fluid [8].

The principle of ORC operation and the usual Rankine cycle are the same, namely the compression of the working fluid, fluid-phase changes (evaporation) in the evaporator, turbine expansion, then changes in the fluid return phase (condensation) on the condenser [9]. The main components in ORC can be illustrated in the following diagram:

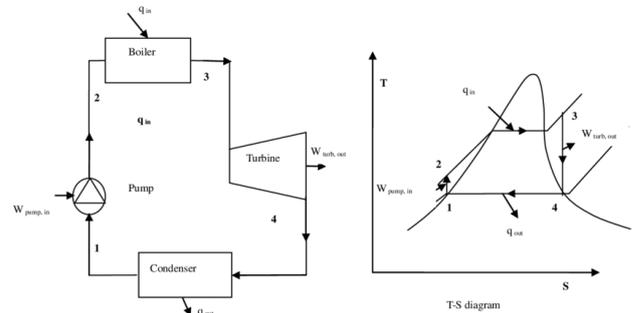


Figure 1 Organic Rankine Cycle System [10]

In some ORC designs, a superheater is used to reheat the working fluid used.

Calculation of the ORC system in the picture above can be done with the following analysis:

1. The process in the turbine that is at the inlet (3) and outlet (4) can be determined by the equation:

$$\dot{W}_t = \dot{m} \times (h_3 - h_4) \times \eta_t \tag{1}$$

2. The condenser process is inlet (4) and outlet (1). The heat dissipated in the condenser can be calculated by the equation:

$$\dot{Q}_c = h_4 - h_1 \tag{2}$$

3. The process at the pump is at the inlet (1) and outlet (2). Pumping work can be calculated by the equation:

$$\dot{W}_p = \dot{m} \times (h_2 - h_1) \tag{3}$$

4. The process in the evaporator is at the inlet (2) and outlet (3). The average heat given by an evaporator to a working fluid can be determined by the equation:

$$\dot{Q}_e = \dot{m} \times (h_3 - h_2) \tag{4}$$

5. The efficiency of the ORC cycle can be calculated by the equation:

$$\eta_{cycle} = \frac{w_t - w_p}{Q_e} \tag{5}$$

6. The thermal efficiency of the ORC cycle can be calculated by the equation:

$$\eta_{cycle} = \frac{(h_2 - h_3) + (h_1 - h_4)}{(h_2 - h_1)} \quad (6)$$

7. Back Work Ratio can be determined by the equation:

$$bwr = \frac{\dot{W}_p}{\dot{W}_t} \quad (7)$$

## 2.2. Low-Temperature Geothermal Power Plant with ORC

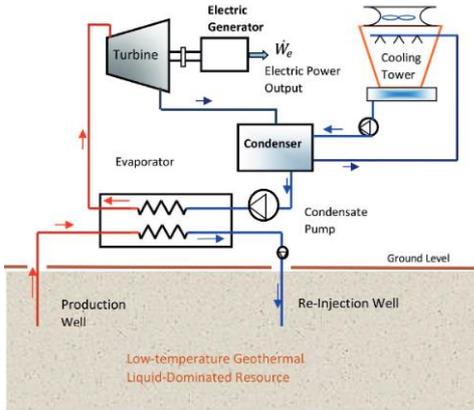


Figure 2 Low-Temperature Geothermal Power Plant with ORC [11]

In this system, the primary working fluid, namely geo-fluid (brine) is extracted from existing resources and channeled to the plant through the production well. Geo-fluid will carry heat which will then be transferred to the secondary/binary working fluid which has a low boiling point using a heat exchanger. Then, the secondary working fluid will evaporate which will be channeled to the turbine.

The turbine is coupled with an electric generator that will convert mechanical energy into electrical energy. After that, the working fluid will be cooled in the condenser before being channeled back to the evaporator so that the cycle repeats [11].

One of the most important things in the performance of low-temperature geothermal plants is the optimal selection of working fluids. Organic fluids used in binary ORC plants have lower boiling points compared to water and high vapor pressure at low temperatures compared to water vapor. Commonly used organic fluids are pure hydrocarbons (for example pentane, butane, and propane), refrigerants (examples: R134a, R218, R123, R113, and R125), or organic mixtures. The optimal energy conversion rate in low-temperature geothermal power plants with ORC depends on the type of organic fluid used in the system [11].

The overall efficiency of the system can be calculated using the following calculation [11].

$$\eta_{th} = \frac{\dot{W}_{net,out}}{\dot{Q}_{geo,in}} \quad (8)$$

And also

$$\eta_{th} = 1 - \frac{\dot{Q}_{cond}}{\dot{Q}_{geo,in}} \quad (9)$$

To calculate the actual output power the following calculation can be used.

$$\dot{W}_{net,act} = \left(\frac{1}{278}\right) [(0.18T_{geo,in} - 10)\dot{Q}_{geo,in}] \quad (10)$$

The estimated output power provided by low temperature geothermal power plants can also be calculated by the equation

$$\dot{W}_{net,act} = \left(\frac{1}{278}\right) [(0.18T_{geo,in} - 10)\dot{Q}_{geo,in}] \quad (11)$$

## 2.3. Levelized Cost of Electricity (LCOE) Calculation

The LCOE can be calculated by using the following equation [16]:

$$LCOE = \frac{CC * CRF}{8760 * CF} + \frac{FOM Cost}{8760 * CF} + \frac{(Fuel Cost * Heat Rate) + VOM Cost}{8760 * CF} \quad (12)$$

Where:

- CRF = Capital Recovery Factor
- CF = Capacity Factor
- CC = Capital Cost (\$/kW)
- FOM = Fixed O&M (\$/kW.year)
- VOM = Variable O&M (\$/kWh)

The unit for fuel cost is \$ / MMBtu and the heat rate is Btu / kWh

The CRF (Capital Recovery Factor) calculation is performed to obtain the price multiplier factor to calculate each equal payment each year. CRF can be calculated using the following equation:

$$CRF = \frac{i(1 + 1)^n}{(i + 1)^n - 1} \quad (13)$$

Where:

- i = interest rate
- n = power plant's lifetime

## 3. METHODOLOGY

### 3.1 Data

This paper uses two types of data: primary data and secondary data. The primary data is taken out directly

from the simulation with the Ebsilon Professional and Thermolib software. Meanwhile, the secondary data is taken out from literature studies related to research topics and titles, such as scientific journals, final projects, theses, monitoring reports, or official documents issued by certain governments or agencies. The geothermal data of the geothermal site is obtained from JICA's preparatory survey for Tulehu geothermal power plant [12].

### 3.2 Method and Instrumentation

The method used for this analysis is as follows:

1. Literature study on Organic Rankine Cycle and its applications, suitable working fluids used in power generation systems with low temperature and enthalpy sources, and geothermal potential at the site to be studied.
2. Analysis of the characteristics of geothermal sources by using methods of determining geothermal potential.
3. Modeling the components contained in a Geothermal Power Plant (PLTP).
4. Determine the parameters of the components in the generator in accordance with the reference.
5. Simulation of generator design using EBSILON Professional and Thermolib software.
6. Analyze the system and optimize efficiency by adjusting the components and parameters.
7. Determine the potential of electrical energy generated from geothermal sources in the place to be studied.
8. Calculate the cost of electricity generation based on the most efficient design.

The instruments that are used for this analysis are Microsoft Excel, Ebsilon Professional and Thermolib. Microsoft Excel is used for data analysis meanwhile the Ebsilon Professional and Thermolib are used for simulation.

### 3.3 Experiment

Modeling the design of Geothermal Power Plants (PLTP) using EBSILON Professional and Thermolib software. The generating model refers to the Organic Rankine Cycle. Geothermal source conditions with low enthalpy and temperature are used. Modeling of generator components such as turbines, pumps, condensers, and evaporators is carried out with the aim of obtaining the design of the generator with the highest

efficiency. Then, the selection of working fluid refers to the study of literature or the use of software, for example, REFPROP NIST or IAPWS-IF 97. Thermodynamic values in cycles such as pressure, temperature, entropy, enthalpy, mass flow rate, etc. are obtained through literature studies and sources from those who have already surveyed the place to be investigated. After the simulation is done, the variables are changed and seen sensitivity to the efficiency of the generating system so that a generator system with the highest efficiency can be designed.

## 4. RESULT

### 4.1 Simulation

There are three model plants that are simulated. The first is the basic ORC model, the second is ORC with a recuperator, and the third is ORC with a recuperator and a preheater.

In general, a recuperator and preheater are installed to preheat the liquid before the Main Heat Exchanger, recovering heat from the outlet flow of the turbine [13]. The use of a recuperator and preheater essentially can increase both the cost and thermal efficiency [13].

The simulations were carried out with the specifications shown in the table below:

**Table 1.** Simulation Specifications

No	Parameter	Unit	Value
1	Max temperature	°C	133.5
2	Max Pressure	Bar	9
3	Min Pressure	Bar	1.85
4	Condenser Pressure	Bar	1
5	Condenser Temperature	°C	26
6	Geothermal fluid mass flow rate	kg/s	248.889
7	Working fluid mass flow rate	kg/s	65.5
8	Turbine efficiency	%	90
9	Pump efficiency	%	80
10	Recuperator and preheater efficiency	%	80

Table 2. Simulation Results

System	Component	Power Output (kW)		Efficiency (%)	
		Ebsilon	Thermolib	Ebsilon	Thermolib
I	Evaporator, Turbine, Condensor, Pump	1682.479	1677.491	11.464	11.32
II	Evaporator, Turbine, Condensor, Pump, Recuperator	1650.084	1634.12	11.722	11.78
III	Evaporator, Turbine, Condensor, Pump, Recuperator, Preheater	1857.864	1813.504	12.67	12.69

Based on all the simulations that have been carried out, a comparison is obtained between the simulation results shown in table 2.

From table 2, the simulation results using both Ebsilon Professional and Thermolib provide simulation results that are not much different, so the data obtained can be validated. The differences in simulation results occur due to differences in the characteristics of the components used, which cannot be compared because of differences in design platforms.

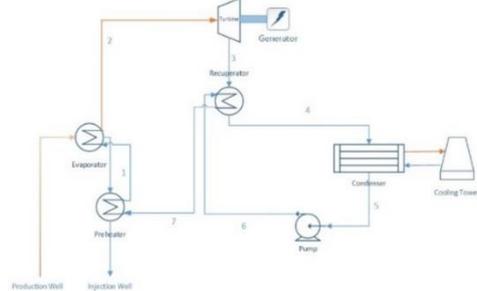


Figure 3 ORC Plant with a Recuperator and a Preheater

The highest efficiency is obtained in an ORC system with a preheater and recuperator, which is around 12.6%, with an output power of around 1800 kW. This can occur because the use of these components increases energy absorption in the system so that energy from a geothermal fluid is not much wasted. The use of a recuperator and preheater can also facilitate the work of the evaporator because the working fluid has reached a higher temperature before entering the evaporator to experience the evaporation process. With these efficiencies, this design matches the reference, namely ORC with a working temperature between 76.85-176.85 °C will have an efficiency of 5-15% [14].

Based on the result above, using the most efficient design, assuming that every house needs 900 W of

power, the power plant will be able to electrify around 2000 homes or 67% of all houses in Tulehu village

Then, the plant cost analysis is calculated using LCOE to determine the economic feasibility of developing one type of power plant compared to other types.

### 4.2 Cost Analysis

#### 4.2.1. Capital Cost

Based on the 2010 EPRI technical report, the capital cost of the geothermal resources is \$833,365/kW. Meanwhile, the plant capital cost is \$3,538/kW.

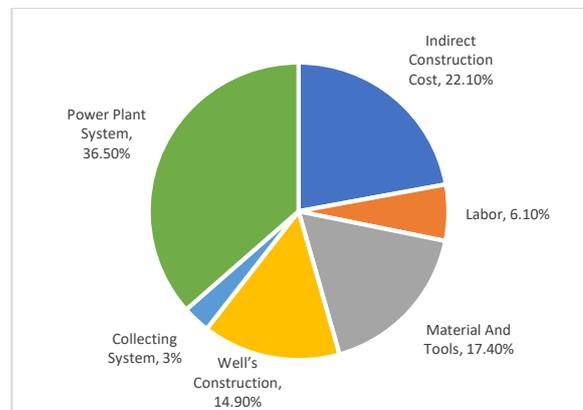


Figure 4 Distribution of Capital Cost

#### 4.2.2. O&M Cost

- In the operation and maintenance calculations, there are two types of costs that are calculated, namely fixed costs and variable costs.
- The calculation of fixed costs includes labor and materials for repairs. Whereas the calculation of

variable costs includes the use of chemicals and annual royalty payments

- According to the reference, O&M fixed costs are \$ 70 / (kW.year), while the O&M variable cost is \$ 4 / MWh.

#### 4.2.3. Investation Cost Estimation

Based on the calculation of the capital cost of geothermal resources and generators as well as operating and maintenance costs, the total investment costs for the construction of an ORC plant with a power of 1800 kW are as follows:

**Table 3.** Details of Investation Cost Estimation

Cost Type	Detail	Investation Cost
Capital Cost	<i>Geothermal Resource</i>	\$833,365/kW
	Power Plant	\$3,538/kW
<i>Total Capital Cost</i>		\$4,371/kW
O&M Cost	<i>Fixed Cost</i>	\$70/kW.year
	<i>Variable Cost</i>	\$0.004/kWh

By using the inflation calculator in US dollars, it is found that the capital cost this year is \$ 5,139.40 / kW, with a cumulative inflation rate of 17.6% [15].

#### 4.2.4 LCOE Calculation

- Plant lifetime : 30 years
- Discount rate : 8%
- Capacity Factor : 85%

Using equation 12 and 13, the LCOE is calculated as follows:

With  $i = 0.08$  and  $n = 30$  years, the CRF is:

$$CRF = \frac{0.08(1 + 1)^{30}}{(0.08 + 1)^{30} - 1} = 0.088827$$

So, the LCOE is:

$$LCOE = \frac{5139.4 * 0.088827}{8760 * 0.85} + \frac{70}{8760 * 0.85} + 0.004$$

$$= \$0.0747/kWh$$

Based on the above calculations, it was found that the LCOE of the generator design was \$ 0.0747 / kWh or Rp. 1,093.94 / kWh (conversion based on an exchange rate of \$ 1 = 14,832.50), it is 64% times lower

than the basic cost of electricity production in Ambon city, Maluku.

## 5. CONCLUSIONS

1. Tulehu geothermal sources can be used as energy sources for power plants with low-temperature ORC systems. The source used is the TLU-01 exploration well with its geothermal fluid characteristics, namely 3 bar pressure, temperature 133.5 ° C, and discharge 238.89 kg / s.
2. The use of a preheater and recuperator in the generation system can increase cycle efficiency. The highest efficiency is obtained in systems with a preheater and recuperator of 12.6%. The power generated from the generation system with the highest efficiency is around 1800 kW.
3. In the design of the generator with the highest efficiency, R245FA work fluid is used with a maximum temperature of 133.5 ° C, a maximum pressure of 9 bar, a minimum pressure of 1.85 bar, and a mass flow rate of the working fluid of 65.5 kg / s.
4. Assuming the power demand of each house is 900 W, the design of the power plant is capable of electrifying around 2000 homes.
5. The cost per kWh of generation using the ORC system is Rp. 1093.94, or 64% lower than the basic cost of electricity production in Ambon city, Maluku.

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