

Performance Analysis of Direct Contact Spray Condenser at Geothermal Power Plant

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Abstract - Geothermal Power Plants utilize geothermal energy to generate electricity through steam turbines. A direct contact condenser is employed to convert exhaust steam from the turbine into water by means of condensation using sprayed cooling water. This report presents a thermal performance analysis of the direct contact condenser at Geothermal Power Plant, focusing on heat transfer effectiveness based on parameters such as the mass flow rates of steam, cooling water, and condensate. Calculations were performed to determine the condenser's efficiency using daily operational data. The analysis revealed an average condenser efficiency of 78.51%, with a maximum of 84.04% and a minimum of 72.05%. Factors such as ambient temperature and cooling water flow rate significantly influence condenser performance. This evaluation is crucial for enhancing the overall efficiency of the power generation system at the Geothermal Power Plant.

Keywords: Condenser, Direct Contact Condenser, Geothermal Power Plant, Efficiency.

I. INTRODUCTION

Indonesia's geographical position at the convergence of several major tectonic plates grants it abundant geothermal resources, making it one of the richest countries in the world in terms of geothermal potential. With nearly 40% of the world's reserves, Indonesia possesses an estimated 28,000 MW of geothermal power capacity. Despite this vast potential, the contribution of geothermal energy to the national electricity supply remains relatively small, amounting to only about 1,189 MW. This occurs in the context of a national electrification ratio of 65%, highlighting the untapped opportunity in geothermal development [1].

Geothermal power plants operate similarly to conventional steam power plants, but use natural steam from the Earth instead of boiler-generated steam. A key component is the condenser, which condenses steam into liquid to sustain the Rankine cycle. Direct contact condenser that mixes steam

with cooling water, offering high thermal efficiency and low maintenance, though its performance depends on thermal parameters like temperature, pressure, and flow rates [2].

1.1 Background

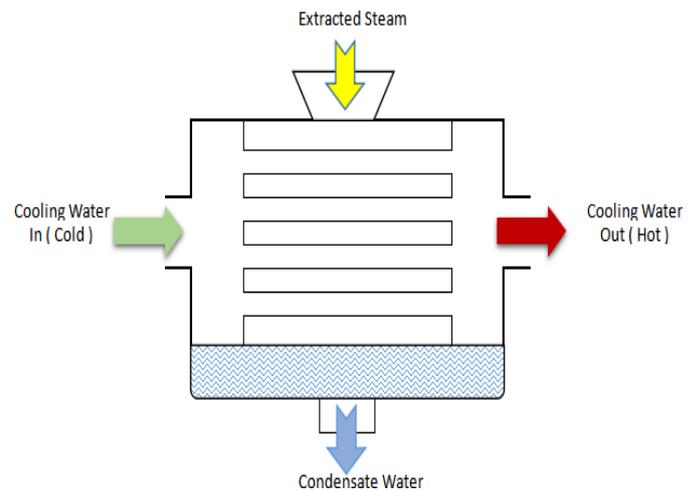


Figure 1: Working Principle of a Condenser [3]

The condenser is a key component in geothermal power plants, converting exhaust steam into liquid by transferring heat to cooling water. This process lowers condenser pressure, increases turbine efficiency, and enhances overall plant performance, enabling more electricity generation with less geothermal energy, benefiting both economy and environment [3].

A direct contact condenser allows steam and cooling water to mix directly without a physical barrier like tubes. Condensation occurs through direct contact, typically using water. This type of condenser is commonly used in geothermal power plants, ocean thermal energy systems (OTEC), and food processing industries. Designs may vary by application and often include features like baffles or nozzles to enhance efficiency.



Figure 2: Condenser

Condensers are classified into two types based on heat transfer: direct contact and surface (indirect contact) condensers. At Geothermal Power Plant, a direct contact condenser is used, where cooling water is sprayed directly onto steam. The cooler water absorbs heat, causing the steam to condense into liquid. The resulting mixture of condensate and cooling water is collected in a hotwell. The condenser consists of two main sections: a condensation chamber for converting steam into water, and a gas cooling chamber to lower the volume of non-condensable gases, reducing the size requirement for the ejector system.

To maintain low pressure (vacuum) within the condenser, the water level in the hotwell must be controlled; levels that are too high or too low can disrupt spraying or damage the pump. Non-condensable gases must also be continuously removed to sustain vacuum conditions. Shows that the condenser operates at very high efficiency—sometimes exceeding 100%—indicating the presence of additional heat input not accounted for in efficiency calculations, likely due to external thermal factors.

1.2 Research Objective

The problem statements addressed in this internship report focus on understanding the working principle of the condenser in Geothermal Power Plant. It also aims to determine how to calculate and identify the efficiency value of the direct contact condenser's performance at the power plant. Additionally, the report seeks to explore which variables influence the effectiveness of the condenser's operation.

The objectives of this study are to analyze the thermal efficiency of the direct contact condenser at Geothermal Power Plant based on thermodynamic parameters, and to evaluate the impact of operational variables such as temperature, pressure, and flow rate on the condenser's effectiveness. Additionally, the study aims to identify optimization measures that can be implemented to improve the efficiency of the direct contact condenser at the plant.

II. RESEARCH METHOD

The thermal performance efficiency of a Direct Contact Spray condenser greatly impacts the overall system efficiency. A drop in efficiency can lead to higher energy consumption, reduced power output, and potential damage to other components. Data processing involves calculating the mass flow rate of cooling water, the heat absorbed (Q_{in}), and the heat rejected (Q_{out}), based on established thermodynamic equations. In the T-S diagram, steam undergoes several processes from two-phase to dry steam, which is essential for driving the turbine to generate electricity. The initial steam condition typically lies on the saturation curve, shifting slightly if superheated steam is present.

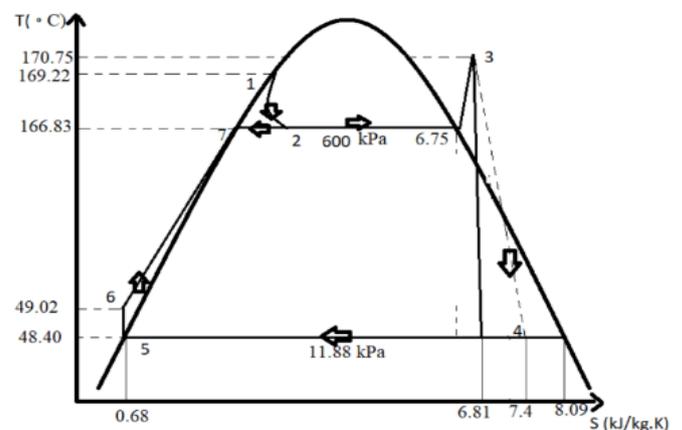


Figure 3: T-S Diagram of Rankine Cycle[4]

The turbine expansion process (1-2) produces output power slightly less than the ideal isentropic expansion (1-2s). The heat rejected from the turbine is released around the condenser and removed via the cooling tower (process 2-3). Condenser efficiency is calculated by comparing the heat entering the turbine as dry steam with the mixed-phase steam exiting to the condenser, where it cools and condenses. The cooling water mixes with the steam and condensate before being recirculated and cooled in the cooling tower, completing the cycle.

Condition 1: This is the initial state as steam enters the turbine, where the phase is saturated vapor. At this point, the values of enthalpy (h_1) and entropy (S_1) are determined using thermodynamic tables based on the given pressure (P_1) and temperature (T_1).

Condition 2: After obtaining h_1 and S_1 , the steam quality (x) can be calculated using the formula:

$$x = \frac{S_2 - S_f}{S_g - S_f}$$

Using the calculated steam quality, the enthalpy at condition 2 (h_2) is determined with the formula:

$$h_2 = h_f(x \cdot h_{fg})$$

Condition 3: At this point, the steam has fully condensed into saturated liquid. The enthalpy at this state (h_3) is found using thermodynamic tables based on the condenser outlet temperature (T_3).

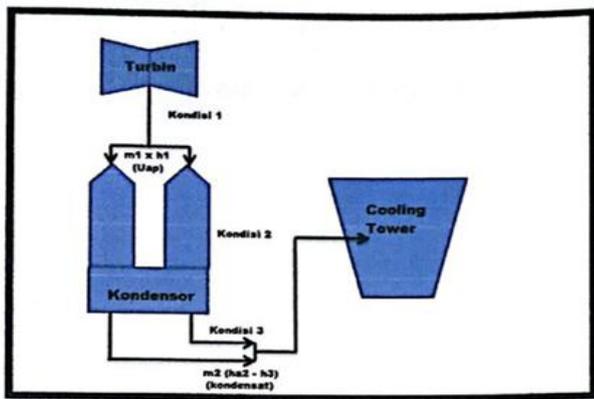


Figure 4: Modeling of Direct Contact Type Condenser

1. Turbine Power Output :

$$W_T = \frac{\text{Generator Load}}{\text{Generator Efficiency}} \quad (1)$$

2. Enthalpy Based on Turbine Power:

$$h_T = (\dot{m}_2 \times h_1) - \frac{W_T}{\dot{m}_2} \quad (2)$$

3. Mass Flow Rate Entering the Turbine:

$$\dot{m}_1 = m_{total} \times \text{steam entering turbine} \quad (3)$$

4. Condenser Efficiency (η):

$$\eta = \frac{Q_{out}}{Q_{in}} \quad (4)$$

$$\eta = \frac{Q_{\text{steam wet}}}{Q_{\text{steam dry}}}$$

$$\eta = \frac{m_2(h_2 - h_3)}{m_1 h_2} \quad (5)$$

When:

W_T = Turbine Power Output (W)

h_T = Specific total enthalpy of the steam – water mixture (kJ/kg)

\dot{m}_1 = Mass flow rate of dry steam entering the turbine(kg/s)

\dot{m}_2 = Mass flow rate entering the condenser(kg/jam)

Q_{out} = Heat released from the condenser (kJ)

Q_{in}

= Heat input to the system before entering the condenser(kJ)

h_3 = Specific enthalpy of liquid after condensation (kJ/kg).

h_2 = Specific enthalpy of wet steam after the turbine (kJ/kg)

η = Efficiency

h_1 = Enthalpi spesifik uap sebelum memasuki turbin (kJ/kg).

m_{total} = Total mass flow rate of the steam – water mixture.

III. RESULTS AND DISCUSSIONS

3.1 Operating Principle of the Direct Contact Condenser

The direct contact condenser functions by spraying cold water directly onto high-temperature, high-pressure steam exiting the turbine. This contact causes the steam to release heat and condense into water. The resulting condensate mixes with additional cooling water and is further cooled before being reused in steam production. Part of this water is also reinjected into the ground to generate new steam. The condenser consists of two chambers: one for condensing steam and another for cooling non-condensable gases, allowing for smaller gas ejector equipment. Low pressure inside the condenser is maintained by regulating water level in the collection tank and continuously removing residual gases.

3.2 Efficiency Calculation

To analyze the performance of a condenser, several key operational parameters are required:

- Steam inlet pressure to the turbine (P_1)
- Condenser vacuum pressure (P_2)
- Steam mass flow rate (\dot{m}_{steam})
- Cooling water outlet temperature (T_{cwout})
- Generator output power (P_G)

The results of these calculations provide a clear overview of the actual performance of the condenser at the Geothermal Power Plant and serve as a basis for evaluating and improving overall system efficiency. The calculation method is based on standard textbook references.

3.2.1 Actual Performance Analysis of the Condenser

The operational condition data used for the following calculations is from September 1, 2017, at 00:00 hours.

$$\begin{aligned} P_1 &= 6 \text{ bar} \\ P_2 &= 0,135 \text{ bar} \end{aligned}$$

$$\begin{aligned} \dot{m}_{uap} &= 230.038 \text{ kg/jam} \\ T_{cwout} &= 53 \text{ }^\circ\text{C} \\ PG &= 55,6 \text{ MW} \end{aligned}$$

It is assumed that all processes operate internally reversible, and each component is analyzed under steady-state operating conditions. The turbine operates adiabatically.

1. Condition 1

Steam inlet pressure to the turbine, $P_1 = 6 \text{ bar}$, based on Table A-5 the corresponding data is obtained:

$$\begin{aligned} h_1 &= 2756,2 \text{ kJ/kg} \\ S_1 &= 6,7593 \text{ kJ/kg}^\circ\text{C} \end{aligned}$$

2. Condition 2

Condenser vacuum pressure, $P_2 = 0,135 \text{ bar}$, Using saturated liquid and saturated vapor data from Table A-5, the corresponding thermodynamic properties are obtained:

$$\begin{aligned} h_f &= 215,701 \text{ kJ/kg} \\ h_g &= 2593,98 \text{ kJ/kg} \\ h_{fg} &= 2378,24 \text{ kJ/kg} \\ S_f &= 0,72319 \text{ kJ/kg}^\circ\text{C} \\ S_g &= 8,04962 \text{ kJ/kg}^\circ\text{C} \end{aligned}$$

Once the required data is obtained, the quality (dryness fraction) can be calculating x :

$$\begin{aligned} x_h &= \frac{h_T - h_f}{h_g - h_f} \\ x_h &= \frac{1828,848 - 215,701}{2593,98 - 215,701} = 0,67 \end{aligned}$$

As determined from the calculations above, the following formula can be applied:

$$\begin{aligned} h_2 &= h_f + (X \cdot h_{fg}) \\ h_2 &= 215,701 + (0,67 \times 2378,24) \\ h_2 &= 1828,848 \text{ kJ/kg} \end{aligned}$$

3. Condition 3

From Table A-4 (saturated liquid), the data obtained are as follows:

$$\begin{aligned} T &= 53^\circ\text{C (Sat Liq)} \\ h_3 &= 221,901 \text{ kJ/kg} \end{aligned}$$

a. Turbine Power Output

$$W_T = \frac{\text{Generator Load}}{\text{Generator Efficiency}}$$

$$W_T = \frac{55,6 \text{ W}}{0,97} = 57,31 \text{ MW}$$

b. Enthalpy based on Turbine data

$$h_T = (\dot{m}_2 \times h_1) - \frac{W_T}{\dot{m}_2}$$

$$\begin{aligned} h_T &= (219.178 \text{ kg/jam} \times 2756,2 \text{ kJ/kg}) \\ &\quad - \frac{(57,32 \text{ MW} \times 1000 \times 3600)}{219.178 \text{ kg/jam}} \end{aligned}$$

$$h_T = 1828,848 \text{ kJ/kg}$$

c. Mass Flow Rate Entering the Turbine

$$\dot{m}_1 = \dot{m}_{total} \times uap \text{ masuk turbin}$$

$$\begin{aligned} \dot{m}_1 &= 230.038 \text{ kg/jam} \times 0,9673 \\ &= 222.515,8 \text{ kg/jam} \end{aligned}$$

d. Mass flow rate entering the condenser

$$\dot{m}_2 = \dot{m}_1 = 222.515,8 \text{ kg/jam}$$

e. Efficiency

$$\eta = \frac{m_2(h_2 - h_3)}{m_1 h_2}$$

$$\eta = \frac{222.515 \text{ kg/jam} (1828,848 \text{ kJ/kg} - 221,901 \text{ kJ/kg})}{222.515 \text{ kg/jam} \times 1828,848 \text{ kJ/kg}}$$

$$\eta = 0,8768 = 87,68\%$$

Based on the calculation results, the condenser efficiency was found to be approximately 87.86%, which is lower than the condenser's design efficiency of 91.68%. This decrease indicates that the condenser is absorbing less heat effectively than originally intended. Such a reduction in heat absorption capacity signifies a decline in the overall performance of the condenser, potentially impacting the efficiency of the entire power generation system.

3.2.2 Factors Affecting the Performance of Direct Contact Condensers

1. Cooling water temperature

The temperature of the water used to cool equipment in the power plant is strongly influenced by the ambient air temperature and the effectiveness of the cooling fans. The

cooler the air, the faster the water absorbs heat, resulting in a lower water temperature. When the temperature difference between the cooling water and the hot steam to be condensed is large, the cooling process occurs more quickly and efficiently, as heat transfers more readily from the hot steam to the cooler water. Cooling fans play a crucial role in this process by circulating air over the water. If the fans do not operate properly, airflow is disrupted, leading to suboptimal cooling performance.

2. Cooling water flow rate

Cooling water plays a vital role in the condensation process by absorbing heat from the turbine exhaust steam and other system components. The greater the flow rate of the cooling water, the more heat can be removed, thereby increasing the efficiency of the condensation process.

3. Equipment lifespan

The average condenser efficiency in September 2017 was 87.86%, compared to the initial efficiency of 91.68%, indicating a decline over time. This condenser has been operating since 1987, so by 2017 it had been in use for 30 years, exceeding the recommended service life of 25 years. The latest overhaul report identified cracks and fouling on the condenser tubes, which likely contribute to reduced performance and pose a risk of leakage.

4. Non-Condensable Gases (NCG).

A condenser must maintain a vacuum to facilitate steam condensation and improve turbine efficiency. One method to achieve this vacuum is by removing non-condensable gases (NCGs) that cannot turn into liquid. These gases cause two main problems: they increase condenser pressure and obstruct heat transfer from steam to cooling water. To address these issues, the gases must be extracted from the condenser, typically using a steam ejector.

IV. CONCLUSION

1. The operating principle of the direct contact condenser at Geothermal Power Plant involves the direct contact between turbine exhaust steam and cooling water sourced from the cooling tower. The cooling water is sprayed through nozzles.
2. The performance of the direct contact condenser at Geothermal Power Plant is evaluated based on its operational efficiency. In September 2017, the average efficiency of the direct contact condenser reached 87.86%.
3. The main factors affecting efficiency are influenced by several variables, including cooling water temperature,

cooling water flow rate, equipment age, and the presence of non-condensable gases (NCG).

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