



Cooling Tower Performance Analysis Using Range and Approach Method Unit 4 in Pt. Pertamina Geothermal Energy Kamojang Area

Ripa Hikmah Ramadan¹, Tasma Sucita¹

¹Electrical Engineering Education Study Program, Electrical Engineering Education University, Jl. Dr. Setiabudi No.229, Isola, Sukasari District, Bandung City, West Java 40154.

*Corresponding Author: Ripa Hikmah Ramadan
Email: ripahikmah18@upi.edu



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Abstract

Geothermal Power Plant (PLTP) is one of the renewable energy sources that supports the national energy transition. One of the important components in the PLTP system is the cooling tower which functions to lower the temperature of the condensed water so that it can be reused in the thermodynamic cycle. This study aims to analyze the performance of the cooling tower at PLTP Kamojang Unit 4 owned by Januari Pertamina Geothermal Januari using the Range and Approach methods based on the ASME PTC 23-2003 standard. Data were obtained from operational logsheets during the period from 4 to 10 January 2025 and analyzed using Microsoft Excel. The parameters observed included inlet water temperature, outlet water temperature, and wet bulb air temperature. The results of the analysis showed that the range value ranged from 35.61°C to 36.48°C, the approach value between 4.73°C to 5.12°C, and the effectiveness of the cooling tower was in the range of 87.42% to 88.52%. These values indicate that the cooling tower is still operating at high efficiency. Daily fluctuations in these values are influenced by environmental factors such as air humidity, wet bulb temperature, and variations in cooling load. In addition, internal factors such as fan conditions, water spraying, cooling water quality, and media packing conditions also contribute to system performance. Based on these results, it is recommended that regular monitoring and preventive maintenance be carried out to maintain the efficiency of the cooling system. With improvements and digitalization of monitoring, the cooling tower at PLTP Kamojang Unit 4 can continue to support power plant operations optimally and sustainably.

Introduction

As Indonesia's population increases, energy needs, including electricity consumption, also continue to increase. In meeting national electricity demand, electricity supply is not only carried out by PT PLN (Persero) but also by private parties, such as Independent Power Producers (IPP), Private Power Utility (PPU), and holders of non-fuel oil (Non-BBM) Operating Permits (IO). Based on data from the 2016 Indonesia Energy Outlook, electricity consumption experienced an average growth of 6.8% per year in the period 2000–2014. In 2014, the national electrification ratio reached 84%, an increase of 3.9% compared to the previous year. It is estimated that in 2025 electricity consumption will reach 1,705 kWh per capita and increase to 3,668 kWh per capita in 2050. National electricity production in 2014 reached 51.61 GW with a contribution of 76% from PLN, 15% from IPP, and 9% from PPU and IO. The projected generation capacity in 2050 is estimated to reach 124 GW, with an

average growth of 5.1% per year. To achieve this target, a larger energy mix is needed from renewable energy sources, one of which is geothermal (National Energy Council, 2016; Tester et al., 2006; Barbier, 2002; Stober & Bucher, 2013; Fridleifsson, 2001; Barbier, 1997; van der Zwaan & Dalla Longa, 2019; Fridleifsson, 2003).

Geothermal Power Plant (PLTP) is a power plant that uses geothermal energy as its main source (Zufar & Azami, 2021; Astro, 2023; Subagio, 2023; Solikah et al., 2023). PLTP utilizes hot steam from reservoirs in the earth to generate electricity. This hot steam is a mixture of gas and liquid phases containing particles, so it requires separation through a scrubber before being flowed to the turbine. The turbine connected to the generator then converts the kinetic energy of the hot steam into electrical energy (Gülen, 2021; Mohseni et al., 2024; Rahimli et al., 2023; Gülen, 2023; Basem et al., 2022).

One of the main components in the PLTP system is the Cooling Tower, which functions to remove heat from the steam condensate that has been used to drive the turbine. The Cooling Tower ensures that the condensation cycle runs optimally so that the cooled water can be reused in the system (Leung & Cheng, 2024; Ghoddousi et al., 2021; Dhamodharan et al., 2024). Cooling Tower efficiency plays an important role in determining the effectiveness of the cooling process. If the performance of the Cooling Tower decreases, the cooling process becomes less than optimal, which ultimately has an impact on the electrical power generated by the PLTP (Abdurohman et al., 2022; Lin & Septyan, 2024; Sofyan et al., 2023; Yanto et al., 2021).

Kamojang PLTP Unit 4, operated by PT Pertamina Geothermal Energy, is one of the providers of environmentally friendly electrical energy in Indonesia. Over time, the Cooling Tower in this unit has experienced various challenges that have caused a decrease in efficiency, so a turnaround is needed to improve its performance again. After the turnaround, an analysis of changes in efficiency is carried out based on certain parameters. Based on this background, this study discusses "Cooling Tower Performance Analysis Using the Range and Approach Methods of Unit 4 at PT Pertamina Geothermal Energy Area Kamojang." This analysis uses historical data calculated with Microsoft Excel in accordance with the ASME PTC 23-2003 standard calculation reference.

Methods

Research Design

This study uses a descriptive quantitative approach that aims to analyze the thermal performance of the cooling tower based on numerical parameters obtained from daily operational data of PLTP Kamojang Unit 4. The focus of this study is on the calculation of Range, Approach, and Effectiveness values as indicators of cooling efficiency, with reference to the technical standard ASME PTC 23-2003. This approach not only describes the numerical value alone, but also evaluates its performance against the performance categories set by the standard. Thus, this research design combines empirical system monitoring and performance interpretation based on industrial technical references.

Participants and Research Location

The study was conducted at PLTP Kamojang Unit 4, located in Garut Regency, West Java, and managed by PT Pertamina Geothermal Energy. This unit is one of the geothermal power plants that uses a direct steam system and is equipped with a counter flow induced draft cooling tower. This study did not involve human participants, but used operational data as analysis material. Data were collected through daily logsheets from the Unit 4 operational technical team during the observation period of January 4–10, 2025. The technical team also helped provide technical information related to the condition of the cooling system during that period.

Research Instruments

Test Materials

The test materials in this study include data on the inlet water temperature to the cooling tower, the outlet water temperature, and the wet bulb air temperature. These three parameters are the basis for calculating the range, approach, and effectiveness, and are collected for seven consecutive days through a daily logsheet.

Testing Tools

Data collection was carried out using measuring instruments such as digital thermometers for water temperature and hygrometers to measure wet bulb temperatures. The data was then processed using Microsoft Excel software to calculate range, approach, and effectiveness values.

Testing Flowchart

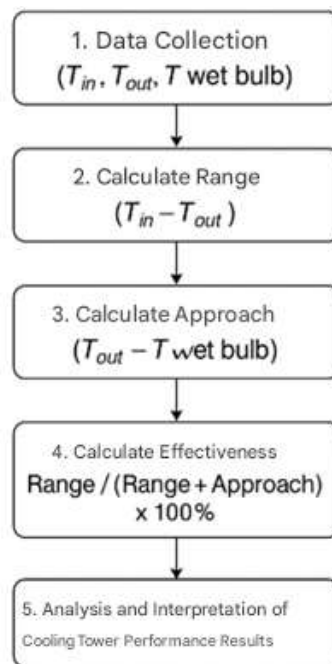


Figure 1. Research Flow Diagram

Data Analysis

Data analysis in this study was carried out systematically to evaluate the performance of the cooling tower based on three main parameters, namely range, approach, and effectiveness. This process begins with the collection of temperature data from the daily operational logsheet of PLTP Kamojang Unit 4, including the temperature of the water entering the cooling tower, the temperature of the water leaving, and the wet bulb temperature during the period of 4–10 January 2025. This data was obtained from the results of the technical team's recording using a digital thermometer and a temperature-humidity measuring device. The flow diagram of data processing and data analysis techniques can be seen in Figure 1.

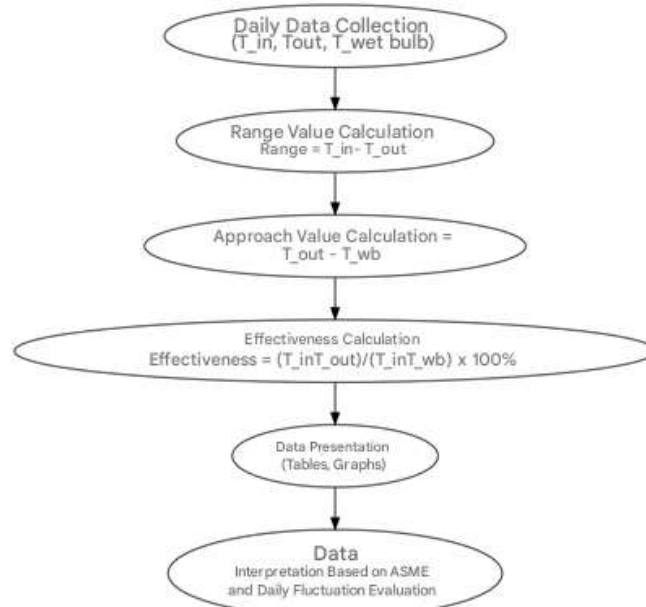


Figure 2. Teknik Pengolahan Data dan Analisis Data

Results and Discussion

Research Findings

Operational data in this study were obtained from daily logsheets for the period from 4 to 10 January 2025, covering the parameters of inlet water temperature, outlet water temperature, and wet bulb air temperature. Recording was carried out every day with standard procedures without intervention, thus providing a real picture of the working conditions of the cooling system. The consistent inlet water temperature value of 60.31°C every day is an important basis for evaluating the effectiveness of the cooling system, because the consistency of this input temperature serves as a valid baseline for comparison of output temperatures. With this basis, analysis can be carried out more objectively on the cooling performance produced by the cooling tower after maintenance (turn around) is carried out.

Table 1. Average Values of Inlet and Outlet Water Temperatures and Wet Bulb Temperatures

Date	Inlet (°C)	Outlet (°C)	Wet bulb temperature (°C)
01-04-2025	60.31	24.28	19.38
01-05-2025	60.31	23.83	19.10
01-06-2025	60.31	24.20	19.36
01-07-2025	60.31	24.70	19.58
01-08-2025	60.31	24.67	19.56
01-09-2025	60.31	24.63	19.53
10-01-2025	60.31	24.54	19.51

Table 1 shows the average measurement data of the inlet and outlet water temperatures from the Cooling Tower and the wet bulb air temperature during the observation period from 4 to 10 January 2025 at the Kamojang Geothermal Power Plant Unit 4. Measurements were carried out every day based on the operational logsheet, as part of the evaluation of the cooling system performance after maintenance (turn around). From these data, it can be seen that the inlet water temperature to the Cooling Tower is constant at 60.31°C every day. The stability of this inlet temperature indicates that the operational conditions of the input from the condensation system to the cooling tower run consistently and are not affected by external fluctuations during the observation period. This is very important to maintain thermodynamic balance in

the overall PLTP cycle. Meanwhile, the outlet water temperature from the cooling tower experienced slight fluctuations from day to day, with the lowest value occurring on January 5, 2025 at 23.83°C and the highest value on January 7, 2025 at 24.70°C. The difference in these values indicates that the cooling tower actively responds to changes in environmental conditions such as humidity and heat load. A low outlet value indicates maximum cooling, while a higher value indicates decreased cooling effectiveness which can be caused by various factors such as less than optimal air circulation, changes in air humidity, or uneven water distribution. The wet bulb air temperature used as a reference for the theoretical cooling limit also shows small variations, ranging from 19.10°C to 19.58°C. This value describes the environmental conditions around the cooling tower which also affect the approach value, which is the difference between the outlet water temperature and the wet bulb temperature. The smaller the difference, the higher the cooling efficiency because the outlet water temperature is closer to the wet air temperature. Through the data in this table, the range (difference between inlet and outlet temperatures) and approach (difference between outlet and wet bulb temperatures) values can be calculated, which are then used to assess the effectiveness of the cooling tower. Evaluation based on these parameters is important in determining whether the maintenance that has been carried out on the system has succeeded in improving cooling performance. This data also serves as a basis for comparison to monitor cooling tower performance periodically in the future and determine operational efficiency standards that can be used as a reference by Kamojang Geothermal Power Plant operators.

Power Generation System at PLTP Unit 4 Kamojang

Kamojang Unit 4 Geothermal Power Plant owned by PT Pertamina Geothermal Energy (PGE) is a 60 MW geothermal power plant that uses high-quality dry steam from the Kamojang reservoir. Steam from the production well is channeled to the Steam Receiving Header to stabilize its pressure, then purified through a separator and demister before entering a double-flow type steam turbine that is directly connected to the generator. The electricity produced has a voltage of 11.8 kV, then its voltage is increased through a step-up transformer and distributed to the national electricity grid. The cooling system uses a direct contact condenser and a closed cooling tower, with condensate water returned to the reservoir through a reinjection well to maintain the sustainability of the resource. This geothermal power plant is also equipped with a gas extraction system to remove CO₂ and H₂S. As an innovation, Kamojang Unit 4 Geothermal Power Plant has developed a Green Hydrogen Plant (GHP) that utilizes condensate water to produce green hydrogen, making it a pioneer in Southeast Asia in utilizing geothermal energy for clean energy.

Calculation of Cooling Tower Performance with Range and Approach Methods

Calculation of the range and approach values on the cooling tower shows a relatively small fluctuation in outlet water temperature throughout the observation period, ranging from 23.83°C to 24.70°C. This narrow daily variation reflects the stability of the cooling tower performance amidst variations in environmental factors such as humidity and heat load. Rather than re-explaining the outlet temperature fluctuations per day in detail, this description can be summarized into a general trend conclusion that the outlet water temperature shows stability and reflects consistent cooling performance. The recorded range values remain high and the approach values remain low throughout the observation, which emphasizes the system's ability to maintain the difference between water temperature and ambient air temperature optimally according to the ASME PTC 23-2003 criteria.

Table 2. Calculation results of range, approach and effectiveness

Date	Range (°C)	Approach (°C)	Effectiveness (%)
01-04-2025	36.03	4.90	88.02
01-05-2025	36.48	4.73	88.52

01-06-2025	36.11	4.84	88.18
01-07-2025	35.61	5.12	87.42
01-08-2025	35.64	5.11	87.46
01-09-2025	35.68	5.10	87.49
10-01-2025	35.77	5.03	87.67

Table 2 shows the calculation results of the range, approach, and effectiveness values of the Kamojang PLTP Unit 4 Cooling Tower system during the observation period from 4 to 10 January 2025. The range value, which is the difference between the inlet water temperature and the outlet water temperature from the cooling tower, shows small variations between days with the highest value of 36.48°C on January 5, 2025 and the lowest value of 35.61°C on January 7, 2025. The high range value indicates that the cooling tower is able to lower the water temperature optimally, indicating that the cooling process is running well. Meanwhile, the approach value, which is the difference between the outlet water temperature and the wet bulb air temperature, also shows insignificant daily fluctuations. The lowest approach value was recorded at 4.73°C on January 5, 2025, while the highest value was 5.12°C on January 7, 2025. The lower approach value reflects a more efficient cooling process because the outlet water temperature is closer to the theoretical minimum temperature limit based on environmental conditions. From the combination of the range and approach values, the cooling tower effectiveness was obtained with a range of 87.42% to 88.52%. The highest effectiveness value also occurred on January 5, 2025, coinciding with the highest range and lowest approach values. This indicates that on that day, the cooling tower worked with the most optimal performance during the observation period. Conversely, the lowest effectiveness was recorded on January 7, 2025, which was also in line with the lowest range and highest approach values, indicating a slight decrease in cooling performance. Overall, the effectiveness value which is always above 87% indicates that the cooling tower is still functioning very well and efficiently. The small fluctuations that occur are still within technically acceptable limits, and are most likely caused by environmental variables such as air humidity and changing thermal loads. This table is an important basis for evaluating system performance and determining future maintenance or optimization steps.

Range

Range is calculated as the difference between the inlet and outlet water temperatures:

$$\begin{aligned}
 \text{Range} &= T_{\text{air in}} - T_{\text{air out}} \\
 &= 60,31 \text{ }^\circ\text{C} - 24,28 \text{ }^\circ\text{C} \\
 &= 36,03 \text{ }^\circ\text{C}
 \end{aligned}$$

The range value during the observation period ranged from 35.61°C – 36.48°C. The highest value was achieved on January 5, 2025 (36.48°C), indicating the most optimal cooling process on that day.

Approach

Approach is the difference between the outlet water temperature and the wet bulb temperature:

$$\begin{aligned}
 \text{Approach} &= T_{\text{air out}} - T_{\text{wet bulb}} \\
 &= 24,28 \text{ }^\circ\text{C} - 19,38 \text{ }^\circ\text{C} \\
 &= 4,9 \text{ }^\circ\text{C}
 \end{aligned}$$

The approach value ranged between 4.73°C – 5.12°C, with the lowest value occurring on January 5, 2025 (4.73°C), which means the cooling process is approaching the maximum theoretical temperature.

Effectiveness

Effectiveness is calculated using the formula:

$$\begin{aligned} \text{Efektivitas} &= \frac{\text{Range}}{(\text{Range} + \text{Approach})} \times 100 \% \\ &= \frac{36,03}{36,03 + 4,9} \times 100 \% \\ &= \frac{3603}{40,93} = 88,02\% \end{aligned}$$

The cooling tower effectiveness range is between 87.42% – 88.52%, with the highest value again occurring on January 5, 2025. This shows that the cooling tower is working with very high efficiency, and the maintenance (turn around) carried out previously has proven to have a positive impact.

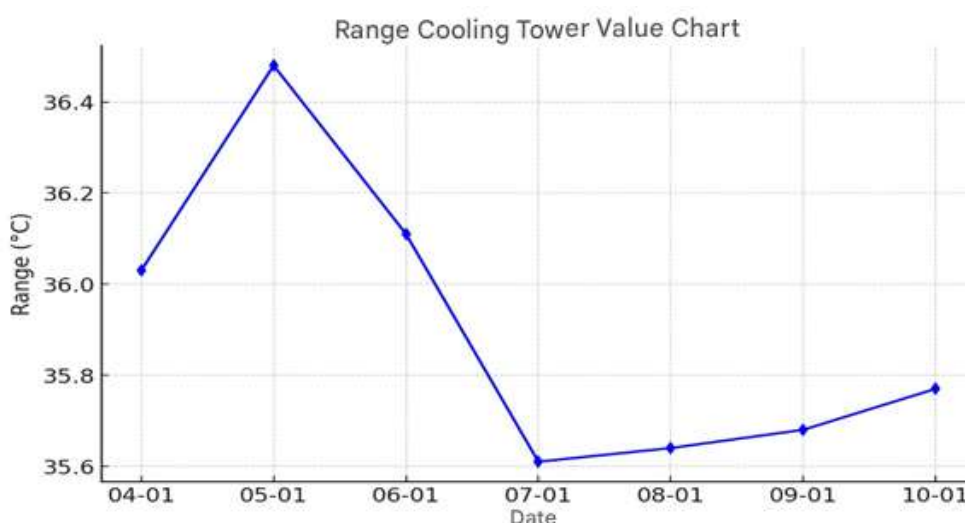


Figure 3. Cooling Tower Range Graph

Based on Figure 3, the Cooling Tower Range value graph from Table 2 data, it can be concluded that the range value on the cooling tower shows that the cooling system performance is still optimal. The highest range value occurred on January 5, 2025 with a value of 36.48°C, which indicates that the difference in inlet and outlet water temperatures is quite large, indicating that the cooling process is running well. Meanwhile, the lowest range value was recorded on January 7, 2025 at 35.61°C, which indicates a slight decrease in cooling effectiveness compared to the previous day. On January 6, 2025, the range value decreased slightly to 36.11°C, which was likely caused by environmental factors such as changes in weather conditions or variations in cooling loads. Fluctuations in this range value can be influenced by several external factors, such as weather conditions, humidity levels, and heat loads that must be cooled by the cooling tower. If it rains or there is high humidity, the temperature of the water leaving the cooling tower tends to be lower, so the range value can change according to the surrounding environmental conditions.

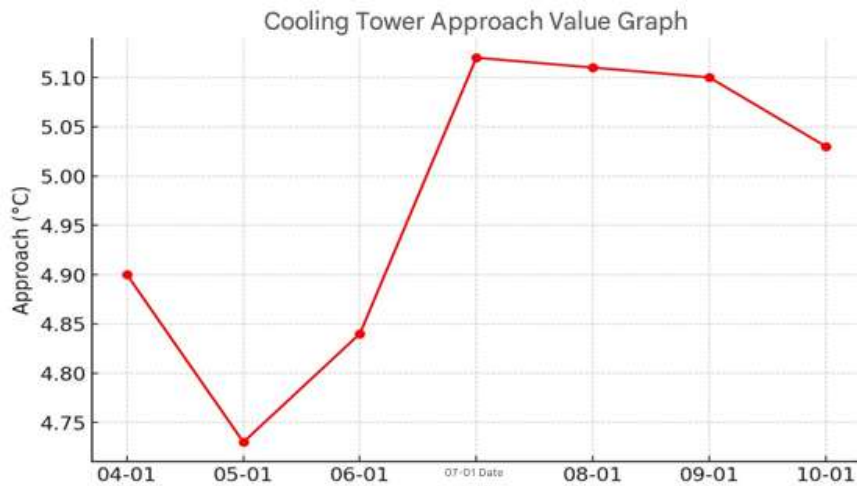


Figure 4. Cooling Tower Approach Value Graph

Based on Figure 4 of the Cooling Tower Approach value graph, it can be seen that the approach value fluctuated during the observation period. The highest approach value occurred on January 7, 2025, which was 5.12°C, which indicates that the difference between the outlet water temperature from the cooling tower and the wet air temperature in the environment was quite large. This may indicate that the cooling effectiveness decreased slightly on that day. Conversely, the lowest approach value was recorded on January 5, 2025, which was 4.73°C, which indicates more optimal cooling because the outlet water temperature is close to the wet air temperature in the environment. In general, a smaller approach value indicates better cooling efficiency, because the water coming out of the cooling tower has a temperature that is closer to the surrounding air conditions. Factors such as weather conditions, air humidity, and cooling load can affect the approach value. If the humidity is high or it rains, the difference between the outlet water temperature and the wet air temperature can be smaller, so the approach value tends to decrease. Conversely, if the environmental conditions are drier and hotter, the approach value can increase because the outlet water temperature from the cooling tower is more difficult to approach the wet air temperature.

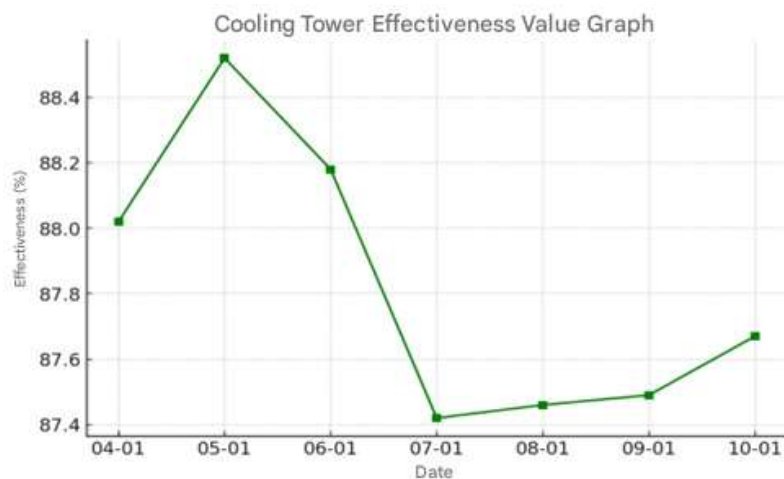


Figure 5. Cooling Tower Effectiveness Value Graph

Based on Figure 5, the Cooling Tower Effectiveness value graph, it can be seen that the effectiveness experienced slight fluctuations during the observation period, but remained in a relatively high range. The highest effectiveness value was recorded on January 5, 2025 with a value of 88.52%, indicating that the cooling tower worked very well in cooling the water. Meanwhile, the lowest effectiveness value occurred on January 7, 2025, which was 87.42%,

indicating a slight decrease in cooling performance compared to previous days. In general, the effectiveness of a cooling tower is calculated based on the difference between the inlet and outlet water temperatures compared to the difference between the inlet water temperature and the wet air temperature in the environment. High effectiveness indicates that the cooling tower is able to optimally lower the water temperature, while lower effectiveness may indicate external factors affecting the cooling process, such as changes in ambient temperature, humidity levels, or heat loads that must be cooled. Although there were slight variations, overall the cooling tower continued to operate with good efficiency during the observation period.

Factors Affecting Cooling Tower Performance Based on Range and Approach Methods

In addition to environmental factors such as humidity and wet bulb temperature, small fluctuations in outlet water temperature during the observation period indicate interesting interactions for further analysis. The narrative does not need to only write that outlet water temperature is related to environmental conditions, but should also be equipped with a correlation coefficient or a visualization of a trend comparison graph between outlet water temperature and wet bulb temperature. Thus, the interpretation of the relationship between these variables becomes more quantitatively robust and can show how much environmental factors influence cooling. This approach will broaden technical insight and support recommendations for future cooling tower operational adjustments if environmental conditions change.

Discussion

Research Discussion

Based on the research results presented in the previous section, a discussion can be carried out on each problem formulation to provide a more in-depth explanation of the meaning of the data obtained, technical implications, and its suitability to the theories and standards used.

Analysis of the Power Generation System at Kamojang Geothermal Power Plant Unit 4

The electricity generation system applied to PLTP Unit 4 Kamojang owned by PT Pertamina Geothermal Energy uses a direct steam generation method that utilizes dry steam from geothermal reservoirs. The steam is channeled directly from the production well to the steam turbine without going through an additional heating process, making this system more efficient and environmentally friendly (Komarov et al., 2022; Eze et al., 2024; Somova et al., 2023; Pérez et al., 2024; Anufriev et al., 2022; Zhang et al., 2016). The turbine used is a condensing type, where after rotating the turbine, the steam is condensed back into water in the cooling tower and then re-injected into the ground to maintain the sustainability of the resource. This system is also equipped with separator equipment and steam cleaners (demister) to ensure that the steam entering the turbine is clean and dry, in order to avoid damage to the equipment (Roy-Aikins et al., 2021; Sperber, 2024; Golwalkar & Kumar, 2022; Liu & Zhang, 2024; Richardson et al., 2013; Carson & Williams, 1980; Sperber, 2024). Overall, this generation system is designed to generate electricity sustainably by utilizing geothermal potential optimally and efficiently.

Analysis of Cooling Tower Performance Calculation with Range and Approach Methods

The analysis of cooling tower performance using the range method and the approach in this study is generally good, but the repeated narratives related to daily fluctuations can be improved. Rather than detailing per day, it is more appropriate to present a statistical summary such as an average outlet water temperature of 24.27°C with a standard deviation of 0.30°C. This summary provides quick information that the variability of the outlet water temperature

is very narrow, and the stability of the system is maintained throughout the week of observation. This kind of statistical information is more concise and at the same time strengthens the conclusion that the cooling tower is functioning well and previous maintenance has successfully maintained cooling performance.

Analysis of Factors Affecting Cooling Tower Performance

Factors affecting cooling tower performance, such as air humidity, air and water flow rates, and fan and cooling media conditions, have been well described. However, to improve the quality of the discussion, it is necessary to further study the relationship between variables quantitatively. For example, calculating the correlation between wet bulb temperature and outlet water temperature, so as not to simply mention a cause-and-effect relationship without more measurable supporting data. Strengthening this analysis will help to formulate more substantial technical recommendations if in the future operational adjustments are needed according to the dynamics of environmental conditions.

Conclusion

The electricity generation system at PLTP Unit 4 Kamojang owned by PT Pertamina Geothermal Energy uses a direct steam system that utilizes dry steam from production wells to directly rotate the turbine. This process takes place efficiently without requiring additional heating, and is supported by a reinjection system to maintain the sustainability of geothermal resources. The performance of the cooling tower at PLTP Kamojang Unit 4 can be calculated using the Range and Approach methods. Range shows the temperature difference between the water entering and leaving the cooling tower, while Approach shows the difference between the temperature of the water leaving and the temperature of the wet ambient air. Both methods provide a simple but effective picture of the efficiency of the cooling system. Factors that affect the performance of the cooling tower based on the Range and Approach methods include wet bulb temperature, air and water flow rates, cleanliness of the cooling tower components, and fan and circulation pump performance. Periodic evaluation of these factors is needed to maintain the efficiency of the cooling system and support the optimization of electricity generation.

Implications

Theoretical Implications Theoretically, this study strengthens the understanding of geothermal power generation systems, especially in geothermal power plants that use the direct steam method. The study of cooling tower performance calculations using the Range and Approach methods also contributes to the development of the theory of cooling system efficiency in power plants. These findings support the concept that cooling system efficiency is greatly influenced by environmental conditions and operational performance, and enrich the literature on electrical engineering and renewable energy in the context of geothermal technology implementation in Indonesia.

Practical Implications Practically, the results of this study can be used as a reference by geothermal power plant technicians and managers in monitoring and evaluating cooling tower performance to maintain electricity generation efficiency. The simple but effective Range and Approach methods can be implemented directly in the field to detect potential declines in cooling system performance. In addition, identification of factors that affect cooling tower efficiency can assist in maintenance planning and technical decision making to improve the operational reliability of the power plant.

Recommendations/Suggestions

For scientific purposes

It is expected that this research can be an additional reference for the development of science in the field of electrical engineering, especially in the study of geothermal power generation systems and cooling systems. In the future, it is recommended that further research be carried out with a more in-depth approach and involving long-term operational data in order to produce a more accurate predictive model regarding cooling tower efficiency and its impact on the performance of the generating system as a whole.

For institutions (PT Pertamina Geothermal Energy)

It is recommended that institutions conduct regular monitoring of cooling tower performance using the Range and Approach method systematically. The implementation of a preventive maintenance system and improving the quality of equipment such as fans, pumps, and cooling media are very important to maintain operational efficiency. In addition, technical training for operators and technicians related to cooling tower efficiency analysis can also improve the response to declining system performance.

For academics or education

It is recommended that universities, especially electrical engineering or renewable energy departments, integrate more real case studies from industries such as the Kamojang Geothermal Power Plant in the curriculum. This will enrich students' understanding of the real application of electricity generation theory and cooling systems, while strengthening the synergy between education and industry.

For further researchers

Further researchers are advised to add other variables such as relative humidity, atmospheric pressure, and automatic control system performance in the cooling tower analysis. Research can also be expanded to other geothermal power plant units to compare performance between units and determine the effect of system design on overall generation efficiency.

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