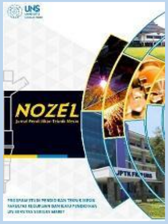

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ANALYSIS OF THE EFFECT OF COOLING TOWER FILLER REPLACEMENT ON COOLING WATER TEMPERATURE, CONDENSER PRESSURE, AND TURBINE POWER OUTPUT AT KAMOJANG UNIT IV GEOTHERMAL POWER PLANT

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Abstract

Cooling tower performance plays a critical role in maintaining condenser vacuum and turbine efficiency in geothermal power plants. This study analyzes the effect of cooling tower filler replacement on cooling water temperature, condenser pressure, and turbine power output at Kamojang Geothermal Power Plant (PLTP) Unit IV, which employs a counter-flow mechanical draft cooling tower. A descriptive, comparative, quantitative method was used to compare daily operational data before (October 2024) and after (December 2024) filler replacement, with turbine load equalized between periods to ensure a valid comparison. The results show that the outlet water temperature decreased by 16%, the range increased by 9%, and the approach decreased by 54%, thereby raising the cooling tower effectiveness from 63.07% to 80.02%. These improvements were followed by a 19% reduction in condenser pressure and a 2% increase in turbine power output, even though the cooling water flow rate declined by 4%, indicating that heat transfer effectiveness has a more dominant influence on system performance than flow rate alone. These findings confirm that filler replacement is an effective preventive maintenance strategy for restoring and enhancing cooling tower performance, thereby improving the overall performance of the geothermal power generation system.

Keywords: *cooling tower, filler replacement, condenser pressure, turbine power, geothermal power plant*

A. INTRODUCTION

Indonesia possesses substantial geothermal energy potential owing to its location along the Pacific Ring of Fire, and Geothermal Power Plants (GPPs) have become one of the mainstays in supporting national energy security as well as the transition toward clean energy (Bina et al., 2018; Suryadarma et al., 2010). The Kamojang Geothermal Power Plant, operated by PT Pertamina Geothermal Energy Tbk, is one of the oldest geothermal fields in Indonesia and has been in operation for several decades. The performance of this power plant is determined not only by main units such as the turbine and generator, but also depends heavily on supporting systems, particularly the "Main Cooling Water System", which functions to cool the condensate water resulting from steam condensation in the condenser.

In Kamojang Unit IV Geothermal Power Plant, water cooling is carried out using a counter-flow mechanical draft cooling tower, which operates based on direct contact between hot water from the condenser and ambient air, causing a portion of the water to evaporate and release heat (Hidayat et al., 2016; Serna-González et al., 2010). The key component determining the effectiveness of this process is the filler (fill media), which functions to expand the contact area between water and air. The problem is that filler performance degrades over the operational period due to fouling, scaling, corrosion, and material degradation (Hajare et al., 2019). This decline in filler performance causes uneven water distribution and a reduction in effective contact area, such that the temperature of the cooling water leaving the cooling tower tends to increase. This condition, in turn, raises the temperature of the water entering the condenser, increases condenser pressure, and potentially reduces the power generated by the turbine (Arefimanesh & Heyhat, 2024).

To address this issue, Kamojang Unit IV Geothermal Power Plant carried out a replacement of the degraded cooling tower filler. However, the extent to which this filler replacement genuinely improves cooling system performance and affects the plant's operating parameters has not yet been quantitatively examined using actual field operational data. The proposed approach to this problem in the present study involves comparing the operational data of the cooling tower and the power generation system before and after filler replacement, encompassing the cooling tower's inlet and outlet water temperatures, condenser pressure, and turbine power output, which are then analyzed using a descriptive comparative approach to determine the magnitude of change that occurs and to relate it to the principles of heat transfer and the Rankine cycle.

Theoretically, the cooling tower functions as a heat sink within the Rankine cycle applied in geothermal power plants, serving as the site where residual heat that cannot be converted into mechanical work is rejected (Moran et al., 2014). The lower the temperature of the cooling water supplied by the cooling tower to the condenser, the greater the heat that can be absorbed from the turbine's exhaust steam, thereby allowing condenser pressure to be maintained at a low level and enthalpy difference between the turbine inlet and outlet to increase, which ultimately raises turbine power output (Ma et al., 2022; Zhou et al., 2019). Cooling tower performance itself is commonly evaluated through the parameters of range, approach, and effectiveness, which collectively describe how closely the actual cooling process approaches its theoretical limit, namely the wet-bulb temperature of the ambient air (Asvapoositkul & Treeutok, 2012; Gao et al., 2017). Several previous studies at other geothermal power plants have further demonstrated that filler replacement can improve cooling tower effectiveness, as observed at Dieng Unit 1 Geothermal Power Plant, which recorded an increase in effectiveness following filler replacement (Ghozali et al., 2024), as well as at the Kamojang Geothermal Power Plant, which showed an increase in fill pack effectiveness in a previous study (Qalbi et al., 2024). These studies serve as both the theoretical basis and point of comparison for the present research in analyzing the effect of filler replacement on cooling water temperature, condenser pressure, and turbine power output at Kamojang Unit IV Geothermal Power Plant.

Based on the foregoing description, this study aims to identify the conditions of cooling water temperature, condenser pressure, and turbine power output before and after cooling tower filler replacement at Kamojang Unit IV Geothermal Power Plant, to analyze the comparison and magnitude of changes in these three parameters resulting from filler replacement, and to evaluate the effectiveness of filler replacement in improving cooling tower performance and overall power plant performance.

B. METHOD

This study is a comparative descriptive study employing a quantitative approach, comparing the operational data of the cooling tower and the power generation system during the periods before and after filler replacement in order to determine the magnitude of change occurring in each parameter observed.

The object of this study is the cooling tower of Kamojang Unit IV Geothermal Power Plant, namely a Marley Class 800 model 84250LE5-8.0-4 unit of the counterflow industrial concrete mechanical draft type, consisting of 4 cells with 4 fan units each with a capacity of 186.4 kW per unit. The filler used is Marley DF381 Clog Resistant Film Fill made of PVC, equipped with a Marley XCELplus drift eliminator, with a design inlet water temperature of 51.72°C, outlet water temperature of 26.22°C, and wet-bulb temperature of 21°C.

The data used are secondary data in the form of daily operational data obtained from the central control room of Kamojang Geothermal Power Plant during the period of October 1–December 30, 2024. The parameters collected include the cooling tower's inlet and outlet water temperatures, the ambient air wet-bulb temperature, condenser pressure, turbine power output, cooling water flow rate, and the number of fans in operation. Data for the period before filler replacement were taken in October 2024, while data for the period after filler replacement were taken in December 2024. To ensure an apple-to-apple comparison, the selection of the post-replacement period was adjusted to correspond to a turbine loading condition relatively equivalent to that of the pre-replacement period (an average of 51.85 MW in October and 52.82 MW in December), so that the observed changes would not be influenced by differences in operational load and could be attributed more accurately to the filler replacement.

Data analysis was conducted by calculating three cooling tower performance indicators for each day of observation, namely range, approach, and effectiveness. Range was calculated as the difference between the cooling tower's inlet and outlet water temperatures to determine the amount of heat successfully released. Approach was calculated as the difference between the outlet water temperature and the ambient air wet-bulb temperature to determine how closely the actual cooling process approached its theoretical limit. Qalbi et al. (2024) proposed that effectiveness is calculated by comparing the range to the maximum possible cooling potential that can be achieved, expressed in the following equation:

$$\eta = \frac{T_{in} - T_{out}}{T_{in} - T_{wb}}$$

The average value of each parameter during the periods before and after filler replacement was then compared to obtain the difference and percentage of change. The calculation results are presented in the form of tables and visualized through line graphs to show daily trends and bar charts to compare average values between periods, using Microsoft Excel software.

C. RESULTS AND DISCUSSION

1. Research Results

Based on the processing of operational data from the Kamojang Unit IV Geothermal Power Plant cooling tower during the periods before (October 2024) and after (December 2024) filler replacement, the average values of each observed parameter were obtained as presented in Table 1.

Table 1. Comparison of Cooling Tower Unit IV Performance Before and After Filler Replacement

Parameter	**Before**	**After**	**Difference**	**Change**
T_{in}	52,41°C	49,76°C	-2,64	-5%
T_{out}	29,83°C	25,20°C	-4,62	-16%
T_{wb}	16.5°C	19°C	+2,4	+15%
Range	22,57°C	24,55°C	+1,98	+9%
Approach	13,23°C	6,1°C	-7,1	-53,77%
Efektivitas	63,07%	80,02%	+16,95%	+27%
Condensor Pressure	0,15 *bar*	0,12 *bar*	-0,02	-19%
Turbine Power	51,85 *MW*	52,82 *MW*	+0,96	+2%
Flow Rate	7422,81 m^3/h	7098,35 m^3/h	-324,45	-4%
Fan	4 unit	4 unit	0	-

Based on Table 1, filler replacement had a positive effect on cooling tower performance and the overall power generation system. The average inlet and outlet water temperatures decreased by 5% and 16%, respectively, resulting in a 9% increase in range, indicating an improvement in heat rejection capability. In addition, the approach value decreased by 53.77%, indicating that the outlet water temperature was moving closer to the wet-bulb temperature and reflecting an improvement in cooling performance. This contributed to an increase in cooling tower effectiveness from 63.07% to 80.02%. On the power plant system side, condenser pressure decreased by 19%, from 0.15 bar to 0.12 bar, resulting in improved condenser vacuum conditions and contributing to a 2% increase in turbine power output, from 51.85 MW to 52.82 MW.

Analysis of cooling tower performance was also conducted through the presentation of data in graphical form to observe trends in parameter changes before and after filler replacement. The graphs used consist of line graphs and bar charts. Line graphs were used to show daily trends in parameter changes, while bar charts were used to compare the average values of key parameters before and after filler replacement.

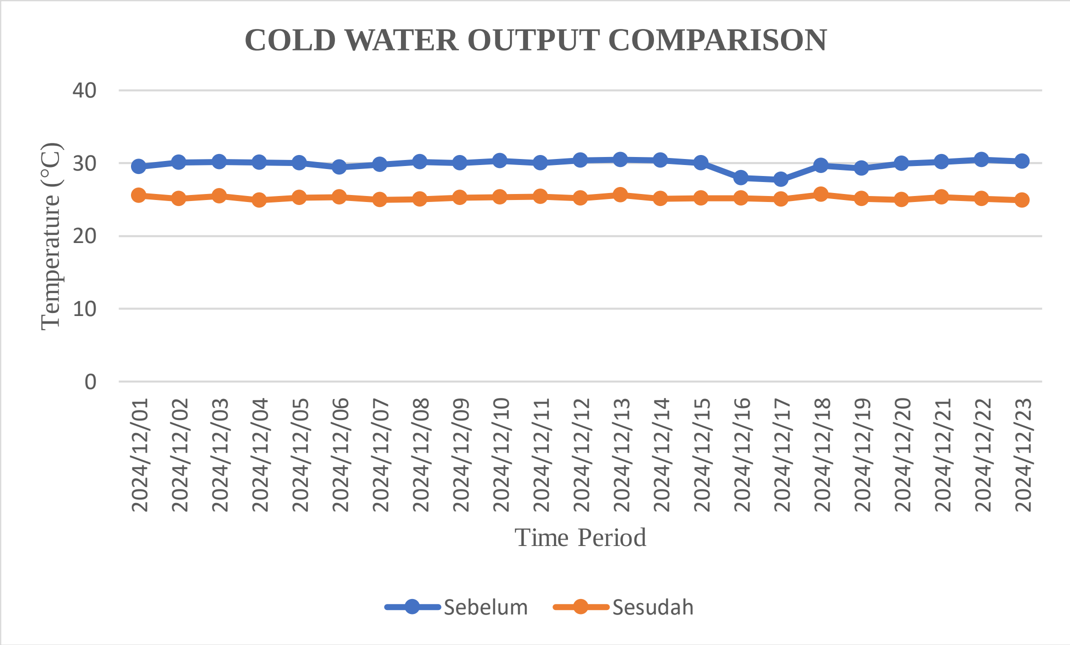

Figure 1. Cold Water Output Comparison Graph

Figure 1 shows the comparison of the cooling tower's outlet water temperature before and after filler replacement. The line graph shows that, overall, the outlet water temperature after filler replacement (orange line) was lower than before replacement (blue line). This decreasing trend was consistent throughout the observation period, with the average outlet water temperature decreasing from 29.83°C to 25.20°C (a decrease of 4.62°C).

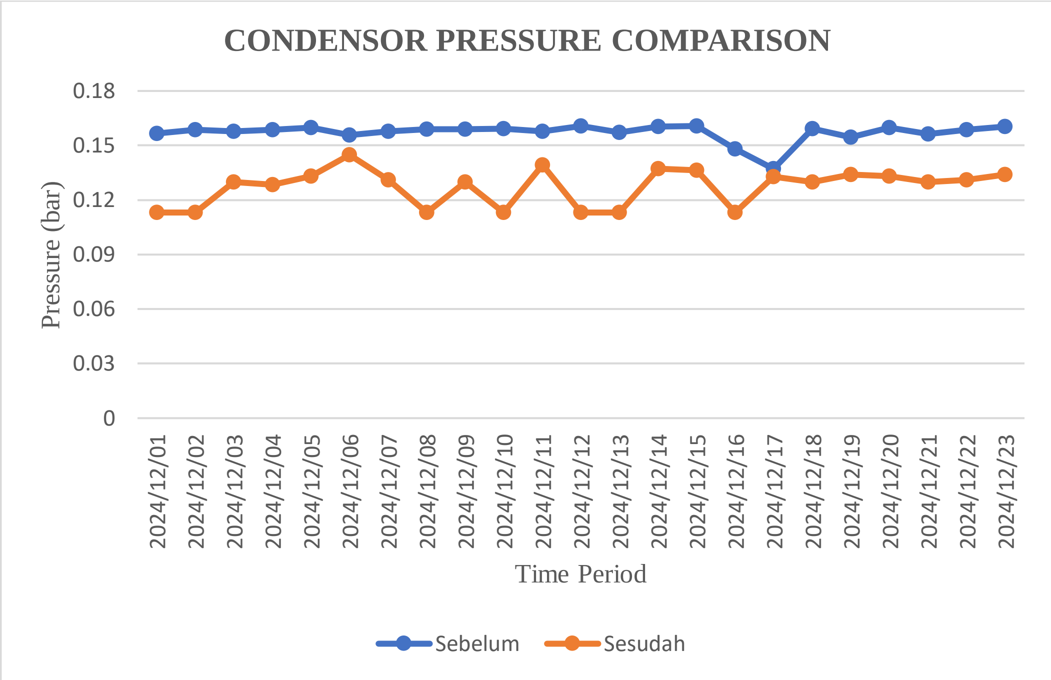

Figure 1. Condensor Pressure Comparison Graph

Condenser pressure decreased substantially after filler replacement, from an average of 0.15 bar to 0.12 bar (a decrease of 0.03 bar). This decrease is consistent with the decrease in outlet water temperature, in accordance with the theory that cooler cooling water improves condensation effectiveness.

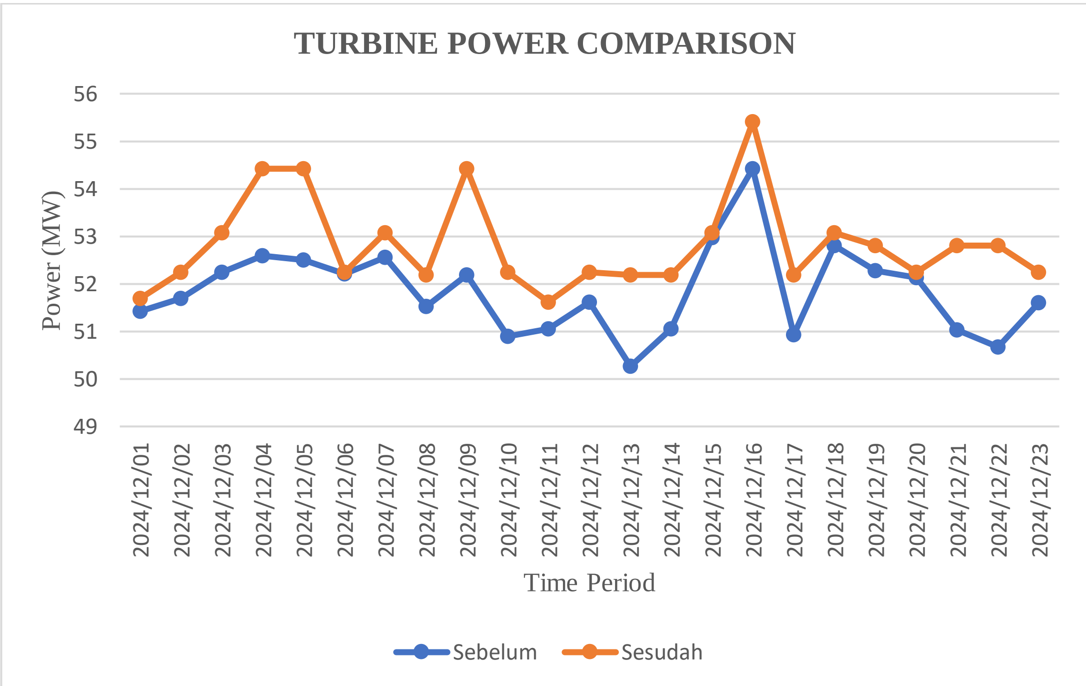

Figure 2. Turbine Power Comparison Graph

The selection of December data for the post-replacement period was based on load equivalence considerations, namely to ensure that the loading conditions of both periods were comparable so that the resulting change in turbine power output would not be influenced by differences in operational load. The graph shows that turbine power output after filler replacement (orange line) was consistently at a slightly higher level compared to the period before replacement (blue line), with an average increase of 0.97 MW (2%). Although the increase was not substantial, this rise nonetheless indicates an improvement in turbine performance that can be attributed to the cooling tower filler replacement, given that load conditions had been equalized.

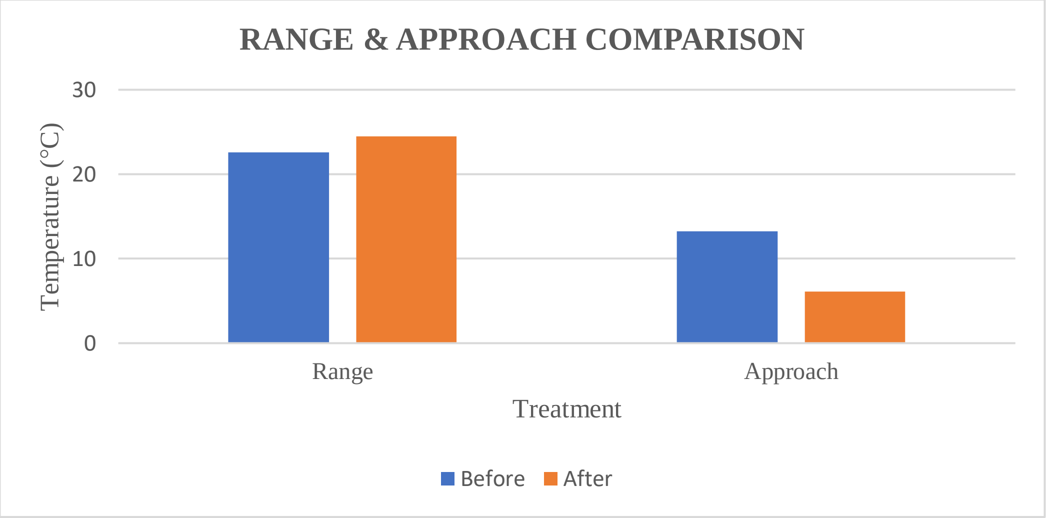

Figure 3. Range & Approach Comparison Graph

Figure 4 shows the comparison of cooling tower range and approach values between the periods before and after filler replacement. The range value increased from 22.5°C to 25.0°C, indicating that the cooling tower was able to reject more heat after the filler was replaced. Meanwhile, the approach value decreased sharply from 14.0°C to 7.0°C. This decrease in approach indicates that the cooling tower's outlet water temperature was moving increasingly closer to the wet-bulb temperature, such that the evaporative cooling process took place more effectively. The combination of increased range and decreased approach directly contributed to the overall improvement in cooling tower effectiveness.

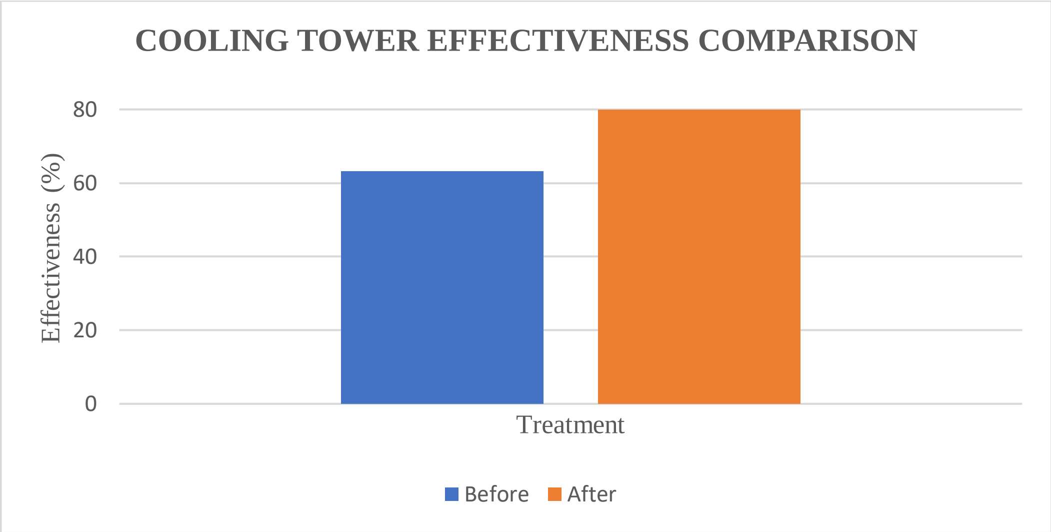

Figure 4. Effectiveness Comparison Graph

Figure 5 shows the comparison of cooling tower effectiveness before and after filler replacement. Cooling tower effectiveness increased from 63.07% (before filler replacement) to 80.02% (after filler replacement). This increase in effectiveness indicates that the filler replacement successfully improved the cooling tower's ability to utilize the available cooling potential. The new, fouling-free filler has a larger contact surface area and is free of scale buildup, allowing the evaporative cooling process to occur more effectively.

2. Discussion

The results of this study answer the research questions posed, namely that cooling tower filler replacement has a significant effect on cooling water temperature, condenser pressure, and turbine power output at Kamojang Unit IV Geothermal Power Plant. The decrease in the cooling tower's outlet water temperature and the increase in effectiveness indicate that the new filler successfully remedied conditions that had previously deteriorated due to fouling and scaling, thereby allowing the heat and mass transfer processes to occur more optimally.

These findings were obtained through a direct comparison of daily operational data across two periods with equalized turbine loading conditions, so that the observed changes in performance can be more convincingly attributed to the filler replacement rather than to variations in load or the number of fans in operation. The calculation of range, approach, and effectiveness using standard cooling tower equations enabled the performance comparison to be conducted quantitatively and objectively.

The observed increase in cooling tower effectiveness is consistent with the principles of the Rankine cycle, in which a lower cooling water temperature enhances the condenser's capacity to absorb heat from the turbine's exhaust steam, thereby allowing condenser pressure to be maintained at a lower level (Ma et al., 2022; Zhou et al., 2019). The decrease in condenser pressure increases the enthalpy difference between the turbine inlet and outlet, which directly enhances turbine work output and the resulting electrical power.

These results are consistent with the study by Ghozali et al. (2024) at Dieng Unit 1 Geothermal Power Plant, which likewise recorded an increase in cooling tower effectiveness following filler replacement, as well as the study by Qalbi et al. (2024) at Kamojang Geothermal Power Plant, which showed an increase in effectiveness after fill pack replacement. Differences in the magnitude of effectiveness improvement across studies, including the present one, may be attributed to differences in the initial degree of filler fouling, the ambient wet-bulb temperature conditions at each location, and other operational variables such as the number of fans in operation (Hajare et al., 2019).

D. CLOSING

Conclusion

Based on the results of the analysis of cooling tower performance before and after filler replacement at Kamojang Unit IV Geothermal Power Plant, it can be concluded that filler replacement significantly improves the performance of the cooling system. This is demonstrated by the decrease in outlet water temperature and the increase in the range value, which indicate that the capacity to release heat to the environment has become more effective. Physically, this condition shows that the new filler is able to increase the contact surface area and improve water distribution, such that the heat and mass transfer process occurs more optimally compared to the previous condition, which had undergone degradation.

In terms of performance parameters, the increase in cooling tower effectiveness indicates an improvement in the system's ability to lower the cooling water temperature. In addition, the decrease in the approach value indicates that the system is now increasingly able to approach the ideal performance limit determined by the wet-bulb temperature. This shows that the heat transfer process occurs more completely, influenced by the improved water distribution and the increased contact surface area of the new filler.

The impact of the improved cooling tower performance is directly reflected in the power generation system, namely through the decrease in condenser pressure and the increase in turbine power output under equalized load conditions. The decrease in condenser pressure indicates an improvement in vacuum quality, which increases the enthalpy difference across the turbine in accordance with the principles of the Rankine cycle, thereby increasing the power generated. The fact that the increase in turbine power output still occurred despite a decrease in flow rate indicates that heat transfer effectiveness has a more dominant influence on system performance than the flow parameter.

Overall, filler replacement has been shown to restore and improve cooling tower performance that had previously degraded. The results of the analysis indicate that the system has now undergone significant improvement, marked by increased effectiveness, decreased approach, and improved condenser pressure and turbine power output.

Suggestions

Based on the results of the research conducted, it is recommended that routine monitoring and inspection of cooling tower filler condition be carried out to detect early signs of fouling, scaling, or damage that could reduce heat transfer effectiveness. In addition, filler performance monitoring should also be conducted indirectly through the analysis of operational parameter trends, such as cold water outlet temperature and range values, so that a decline in filler performance can be identified earlier without the need for direct physical inspection. Furthermore, the use of filler materials with high resistance to fouling and scaling, such as high-performance PVC or composite materials, should be considered to extend filler service life while maintaining heat transfer effectiveness over the long term.

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