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Integrated Mechanical and Chemical Treatment for Maintaining Cooling Tower Performance: A Case study from Muara Laboh Geothermal Field

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ABSTRACT

Cooling towers (CTs) play a vital role in the condensation process of the cooling water cycle in a geothermal power plant. They cool down the water used in the condenser, allowing it to maintain an optimal condensation rate. In geothermal power plants with direct contact condensers, CTs may encounter operational challenges such as sulfur deposition, scaling, biofouling, and mechanical problems that reduce CT efficiency and power generation. Since the past CT performance decline case in mid-2023, Muara Laboh Geothermal Power Plant has successfully established significant improvement programs comprising of proper monitoring system, better cooling water quality management, and mechanical actions. Routine nozzle replacement every 6 months increased CT efficiency by restoring uniform water distribution through fill pack and into basin. In parallel, improvements in chemical treatment—including biocide dosing schedule and sulfur dispersant dosing reliability maintained CT component cleanliness, with CT approach kept below 5°C for extended periods. Following these improvements, plant generation returned to its Plant Rated Capacity of 86.26 MWN. One year after improvement, the load averaged 86.46 MWN. Economically, without program enhancements the plant was projected to generate only 81.95 MWN in mid-2024, causing an estimated 24,310 MWh electricity dispatch deficit or USD 3.1 million revenue loss. This paper highlights the success story of Muara Laboh GPP in preserving CT performance and achieving long-term operational optimization.

1 INTRODUCTION

Muara Laboh Geothermal Power Plant (GPP) is the first double-flash geothermal power plant in Indonesia, which began commercial operation in December 2019. Located in Solok Selatan Regency, West Sumatra, the plant has a gross generation capacity of 90 MW. The power plant utilizes a condensing steam turbine with dual inlet pressures (high-pressure (HP) and low-pressure (LP) steam). The steam passes through the turbine and is then condensed into condensate within a direct contact condenser (DCC). The DCC provide some advantages over the surface condenser which include lower cost, small temperature approach, higher heat transfer performance, and reducing fouling and corrosion concerns (Mahoot et al., 2014). Additionally, the direct contact condenser provides more efficient cooling water utilization, as it eliminates the need for external make-up water in the cooling tower. The make-up water is instead derived from the condensed steam itself. The produced condensate mixes with the cooling water, part of which is reinjected into the reinjection wells. The hot condensate is cooled in the cooling tower to produce cooling water for continuous circulation. Muara Laboh GPP employs an induced draft cooling tower, which provides higher cooling efficiency compared to other cooling tower types like natural draft cooling tower (Sao and Dwivedi, 2021).

In a geothermal power plant that utilizes a condensing steam turbine, the cooling tower plays a crucial role in maintaining the turbine exhaust pressure within the condenser. An increase in exhaust pressure leads to reduced power generation or higher steam consumption, ultimately lowering the plant's overall performance. The primary function of the cooling tower is to remove heat from the cooling water before it returns from heat exchange equipment. However, geothermal steam contains complex and unpredictable chemical compositions. When steam comes into direct contact with cooling water in a direct contact condenser, various types of deposits can form within the cooling water system. Unlike steam in conventional thermal power plants, geothermal steam is not pure, it contains non condensable gases (such as CO_2, H_2S, CH4, NH3, and other residual gases) and trace minerals. These gas components like H_2S, CH_4, and NH_3 can act as nutrients for microorganisms or react through oxidation, leading to biofouling, sulfur deposit and other types of deposits in the cooling water system (Relenyi and Rosser, 2017). These issues present significant challenges that must be addressed to ensure reliable cooling water and cooling tower performance.

In mid-2023, Muara Laboh GPP experienced a rapid decline in cooling tower (CT) performance, where the CT approach increased from 3°C to 5.5°C within just four months. This performance drop was attributed to several issues involving CT components, including the fill packs, spray nozzles, and distribution pipes. It was also identified that the chemical treatment program at the time was not fully effective. Evidence of sulfur deposits and biofouling was found in several fill pack layers, as well as significant scaling on the nozzles. Visually, the cooling tower exhibited uneven water distribution. Based on this experience, several lessons were learned to enhance the maintenance strategy for cooling tower performance. A combination of optimized chemical treatment and mechanical cleaning has since been implemented to maintain stable performance, targeting a cooling tower approach of less than 5°C and a turbine exhaust pressure below 0.085 bara.

This paper describes the successful implementation of mechanical treatment in tackling the decline performance issue and maintained the performance by regularly monitor and carry out mechanical and chemical treatment to guarantee the CT efficiency within the normal range. Some key parameters to be observed are CT approach, CT efficiency, pH, Sulfur deposit thickness on nozzles, and Sulfate concentration. Furthermore, the paper discusses the associated improvement in condenser performance and potential revenue savings, demonstrating how early lessons led to sustained operational reliability and long-term optimization.

2 COOLING TOWER SYSTEM AND CONTINUOUS IMPROVEMENT

2.1 CT Performance Decline Observation

In mid-2023, the appropriate plant performance monitoring system still not established for detailed section by section such as cooling tower approach, pump efficiency, condenser cooling capability, etc. As a result, the degradation of CT performance was not immediately tackled until the generation gradually observed came down from the normal full load set point and can't be attained with the same steam operating parameters.

Subsequently from the detail monitoring and observation for some power plant auxiliaries' performance parameters narrow down to the cooling tower effectiveness. The approach shows inline trend with the plant generation and plant exhaust pressure drop. In March to July 2023 under full load operation, the approach temperature shows gradually increase from 3 to 7 and which lead to Steam turbine exhaust pressure slowly increase from 0.065 bara to 0.085 bara as well as cause the plant generation drop. Exhaust pressure of condenser is directly affected by the cooling water temperature, thus when condenser pressure is getting higher it will immediately attribute to decline of plant performance and plant generation (Bhoi et al., 2015)

Figure 1 illustrates the CT approach temperature trend aligned with exhaust pressure which show the gradual increase profile from March 2023 until the problem was identified in June 2023 and recovered by some corrective actions. This experience become valuable lesson to develop much proper plant performance monitoring subsequently prevent the accidence occurred again.

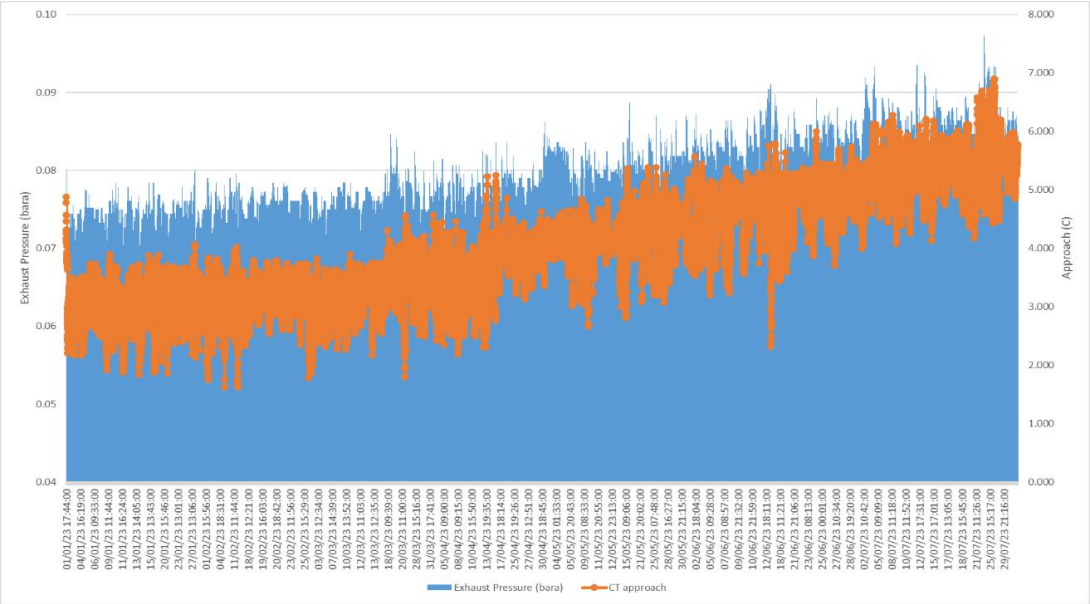


Figure 1. Steam Turbine Exhaust Pressure and Cooling Tower Approach Profile from Jan-Jul 2023

2.2 Field Inspection and Physical Finding

A comprehensive inspection on each CT cell were carried out in response to the performance deterioration in end of July 2023. At the first step, online CT inspection was conducted by observing water distribution pattern for each cell. Clearly the water distribution exhibited the uneven water curtain for almost to all cells (see figure 2). Some issues were found such as clogged spray nozzle, partial damage on fill-pack, crack distribution pipe, and some Thick deposit on CT Nozzles. These findings become turning point to method improvement used in mechanical and chemical treatment programs as well as the plant performance monitoring scheme.

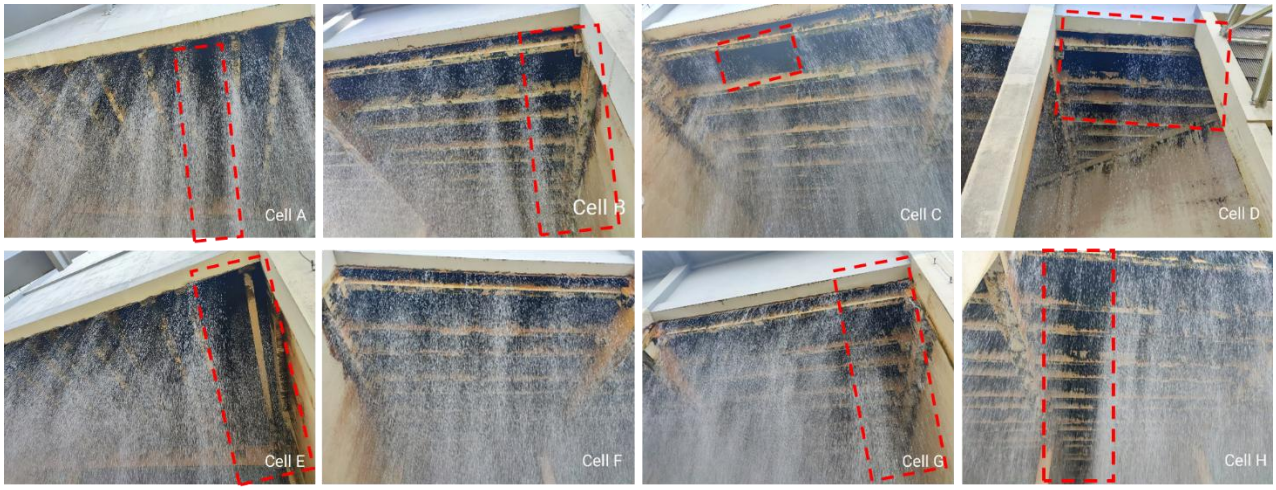


Figure 2. Uneven cooling water distribution found in every Cell of CT

2.3 Improvement Program and Preventive Actions

To prolong the reliability of CT operation in supporting plant generation stability, SEML team applied systematic programs. This incident raised team awareness and prompted the establishment of improved monitoring and corrective actions to prevent similar events in the future. Some programs were set to be implemented such as comprehensive and extensive monitoring on CT notably CT performance parameters and CT visual water distribution appearance, Mechanical preventive maintenance, and Chemical Treatment Optimization. The improvement program was developed not only as a corrective measure but also as a long-term preventive framework. This integrated workflow enables both chemical and mechanical approaches to complement each other in sustaining cooling tower performance.

3 INTEGRATED IMPROVEMENT PROGRAMS

3.1 Comprehensive Monitoring Programs

There have been several indications of cooling tower performance degradation. Following this experience, SEML recognized the need for comprehensive monitoring to ensure the cooling tower (CT) performance remains on track. The key parameter monitored is the CT approach temperature along with visual inspection of the water distribution pattern to assess its uniformity. Both parameters are monitored weekly by the Plant Performance Team and Field Operators. The CT approach maximum limit is set at 5°C (Supreme Energy Muara Laboh & Sumitomo Corporation Consortium, 2018), with 4°C as the warning level. When the approach value exceeds 4°C, the team coordinates with the Maintenance Team and raises a work request if necessary to restore performance before the limit is reached. Visual inspections are executed by taking picture of each cell and check the water distribution evenness, which are later evaluated by the Plant Performance Team to determine the cleaning priority for the next maintenance schedule, ensuring cleaning activities are more effective and targeted. In addition to the CT approach, several other parameters affecting cooling tower performance are also monitored, including cooling water temperature, condenser pressure, and plant generation.

Among these, cooling water temperature and condenser pressure show the strongest correlation with CT performance decline (Bhoi et al., 2015). These parameters are closely reviewed and evaluated and if any deviation from the normal range, condenser pressure above 0.08 bara or cooling water temperature exceeding 25°C are treated as an early indication of potential issues that could impact plant generation. To ensure the effectiveness of chemical treatment in controlling deposit and fouling formation, additional parameters are also monitored, such as sulfate concentration, nitrate concentration, sulfur layer thickness on CT nozzles. The sulfate concentration is maintained between 40–70 ppm, with a stable trend being the key indicator of effective treatment but trend stability remains the most critical aspect.

3.2 Chemical Treatment

Although the chemical treatment system had already been applied prior to the 2023 cooling tower (CT) performance decline, its execution and monitoring were not fully optimized. At that time, irregular biocide dosing schedules and occasional interruptions of sulfur dispersant injection caused by pump cavitation were still observed in the cooling water (CW) treatment system. These inconsistencies potentially reduced the chemical program's effectiveness in controlling biological growth and sulfur deposition within the cooling tower circuit.

3.2.1 Regular Biocide Injection Program

Two types of biocides—oxidizing biocide (Purate) and non-oxidizing biocide (N7330)—are used alternately to control microbial growth and prevent biofilm formation. A fixed 10-day injection schedule was established to ensure consistent dosing regardless of sulfate concentration fluctuations. Optimization trials of N7330 injection frequency demonstrated that both 7-day and 10-day dosing intervals maintained TAB below 3,000 CFU/mL, whereas extending the interval to 14 days led to bacterial instability (3,000–10,000 CFU/mL). Therefore, a 10-day injection interval was identified as the optimal balance between efficiency and microbial control (Ecolab Nalco Water, 2023). This approach maintains biological stability and supports a balanced sulfate trend in the cooling tower water (E. Yanto et al., 2021).

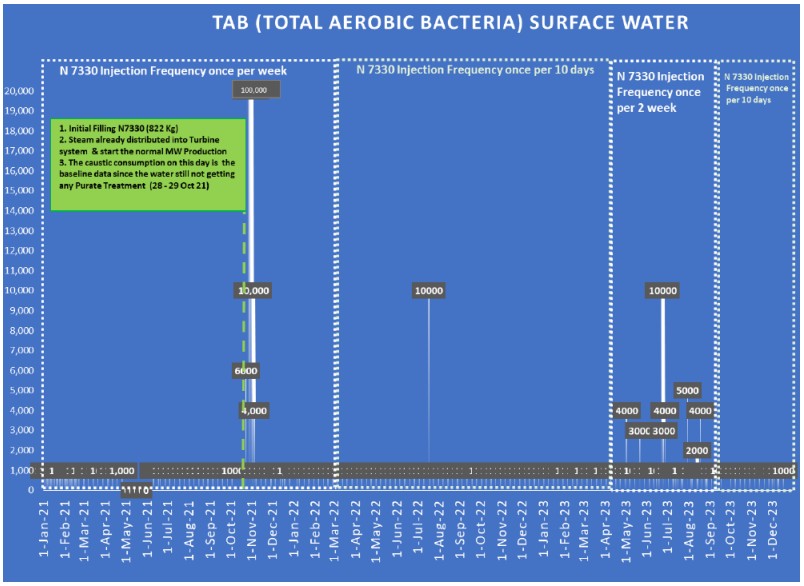


Figure 3. Trend of Total Aerobic Bacteria (TAB) under different N7330 injection frequencies (7-day, 10-day, and 14-day intervals) in the cooling water system from 2021–2023. Source: Ecolab Nalco Water (2023).

Table 1. Chemical used in Cooling Water Treatment

Biocide Type	Chemical Name	Function	Injection Frequency
Oxidizing	Purate	To control algae, fungi & SOB.	Every 10 days
Non-Oxidizing	N7330	To control aerobic and anaerobic bacteria.	Every 10 days

3.2.2 Sulfur Dispersant Dosing Reliability and effectiveness

The sulfur dispersant dosing pump failed several times to supply the chemical due to a low level in the dispersant storage tank, which caused suction issues at the pump, as well as a dirty strainer. The sulfur dispersant functions to disperse sulfur deposits into finer particles and minimize the deposition rate, not to prevent deposit formation (Hidayat and Kuntoaji, 2013), subsequently prolong the good performance of CW system. Sulfur dispersant dosing reliability was improved by installing a level indicator with a low-level alarm mark and incorporating daily tank-level monitoring and timely refilling to prevent pump cavitation. In parallel, pump reliability was optimized through routine maintenance of the suction strainer, including daily visual checks and scheduled cleaning or earlier if clogging occurs. After each refilling or strainer-cleaning activity, operators verify pump operation to ensure stable and continuous chemical flow to the cooling water system.

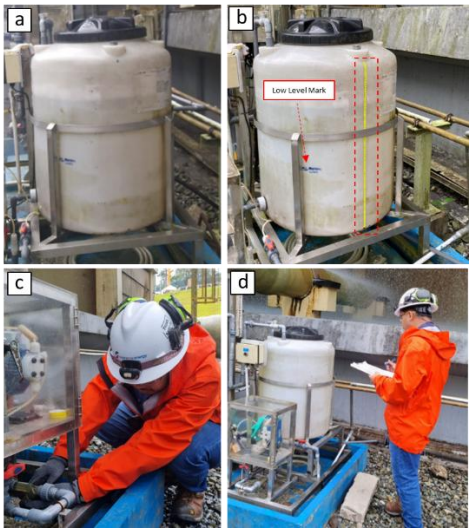


Figure 4. improvement of the sulfur dispersant dosing system. (a) Sulfur dispersant storage tank in its initial condition without a level indicator. (b) The same tank after installation of an external level indicator to enhance monitoring reliability. (c) Operator performing routine daily checks and monthly cleaning of the sulfur dispersant strainer. (d) Operator conducting daily verification of sulfur dispersant level and topping up the chemical when it reaches the low-level mark.

3.3 Mechanical Treatment Programs

Whereas a CT preventive maintenance (PM) schedule already existed, it did not fully cover all critical CT components. The previous PM mainly focused on fan blade angle checks and general visual inspections, without specifically assessing the condition of spray nozzles or other internal components. At that time, routine cleaning and rotation of CT nozzles for each cell had not yet been introduced. According to Ranjan et al. (2019), routine mechanical cleaning and timely replacement of spray nozzles improves cooling tower performance by preventing nozzle clogging and maintaining uniform water distribution. A new preventive maintenance program was introduced with a six-month rotation schedule for each cooling tower cell. In this program, dirty nozzles are removed, cleaned, and replaced with a pre-cleaned spare set. Only one spare set is required per cell, as the cleaned nozzles become the next rotation's spare.



Figure 5. Cooling tower nozzle mechanical cleaning and nozzle replacement. (a) Fouled cooling tower nozzles dismantled from their holders during inspection, (b) Installation of a cleaned spare nozzle, (c) Washing and restoration of fouled nozzles, producing clean spare nozzles ready for next replacement in other CT cells

The introduction of the new program ensures a more effective recovery of cooling tower (CT) cell performance, although it requires slightly longer preventive maintenance (PM) duration. The PM activities are performed while the plant remains online. For example, when CT Cell A is scheduled for PM, the cell is temporarily taken out of service by closing its water distribution valve and stopping its fan. The updated CT PM schedule is presented in Table 2, which outlines both the existing maintenance tasks and the additional activities introduced under the new program, including detailed cleaning and routine nozzle rotation.

Table 2. CT Nozzle Replacement PM Schedule in Semester 1 2024

CT Nozzle Replacement PM Schedule - Semester 1 2024

CT Cell	June																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
CT Cell-A			■																											
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4 RESULT AND DISCUSSION

4.1 Cooling Tower Performance Stability

After integrated mechanical and chemical program maintained, the stable plant performance is achieved. The CT performance always maintained within normal range (CT Approach < 5^{O}C), when the performance begins to reach the limit value, mechanical program is scheduled. With effective chemical treatment, the cooling tower approach rises more slowly and remains around 5°C, allowing CT nozzles to be replaced and rotated only every six months with clean ones.

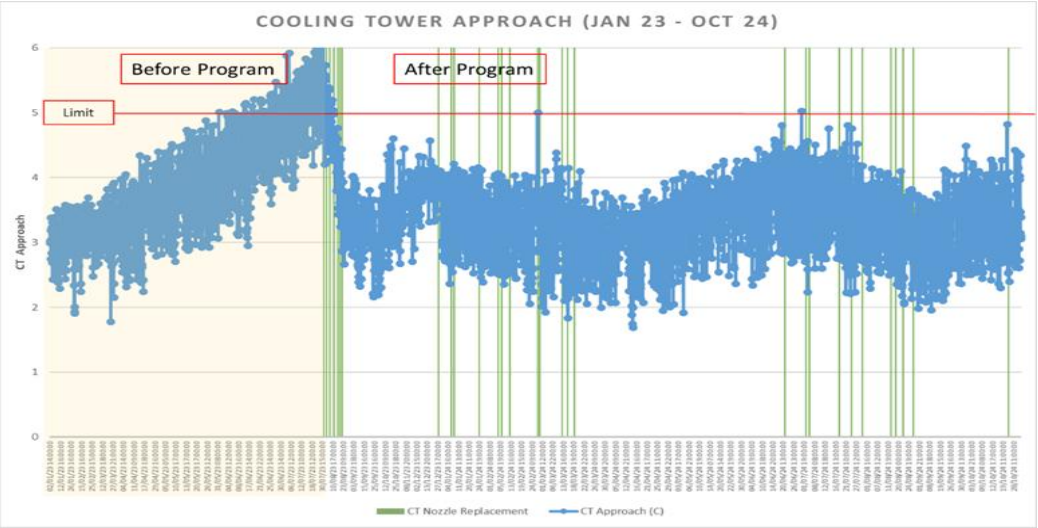


Figure 6. Cooling Tower Approach Temperature Trend (Jan 2023 – Oct 2024)

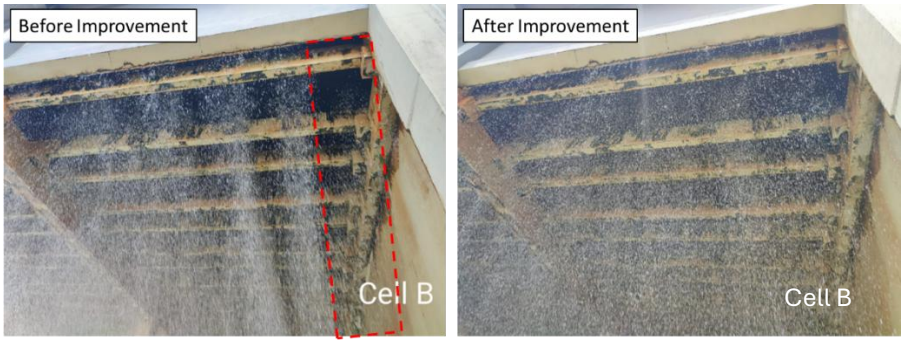


Figure 7. Improvement in cooling tower water distribution

Maintaining the CT approach below 5°C demonstrates that the program has effectively preserved plant performance. This is reflected by the steam turbine exhaust pressure remaining below 0.08 bara, enabling the plant to achieve and sustain full-load generation stably.

4.2 Chemical Parameter Performance Improvement

Chemical dosing reliability, particularly the stabilization of biocide application and sulfur dispersant injection contributed to slowing fouling rates and enhancing long-term cooling water cleanliness. Two key chemical indicators demonstrate this improvement are sulfate concentration in cooling water and sulfur deposit thickness on selected CT nozzles.

Before the dosing reliability improvements, sulfate levels fluctuated widely due to irregular biocide injection. After the introduction of routine fixed biocide dosing schedule every 10 days for N7330 and Purate, the sulfate concentration trend gradually decreased and stabilized.

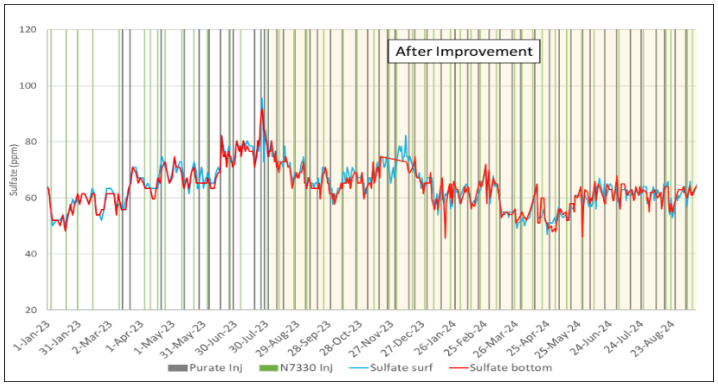


Figure 8. CW Sulfate concentration trend before and after program improvement

To verify the effectiveness of sulfur dispersant on reducing localized sulfur deposition, SEML monitors and measures deposit thickness on some CT nozzles. These nozzles are intentionally excluded from replacement during mechanical maintenance cycles, allowing long-term observation of deposit formation

Measurements conducted in the years prior to dosing optimization showed sulfur deposit thickness reaching up to 3 mm, contributing to nozzle spray distortion and uneven water distribution. After implementing consistent sulfur dispersant injection, the same monitoring points showed significantly reduced deposition, with sulfur thickness maintained in the range of 0–1.5 mm.

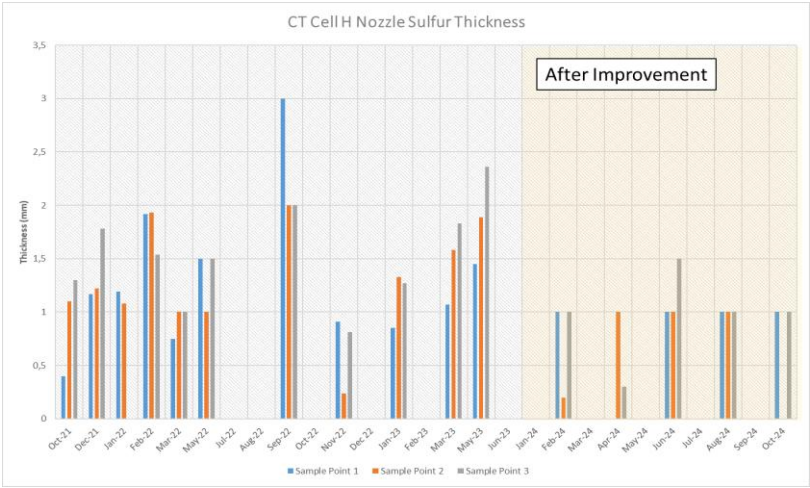


Figure 9. CT Nozzle Sulfur Thickness Trend at CT Cell H before and after Improvement

4.3 Plant Generation Performance

The improvement in cooling tower performance had a direct and measurable impact on overall plant generation. At Muara Laboh Geothermal Power Plant, the operational generation target is 86.26 MWN at minimum when full load operation. After implementing the integrated improvement program particularly, the completion of nozzle

cleaning and rotation across all eight CT cells, the plant was able to restore and sustain generation output at the target value on a consistent basis. This generation recovery occurred in parallel with the stabilization of cooling tower efficiency.

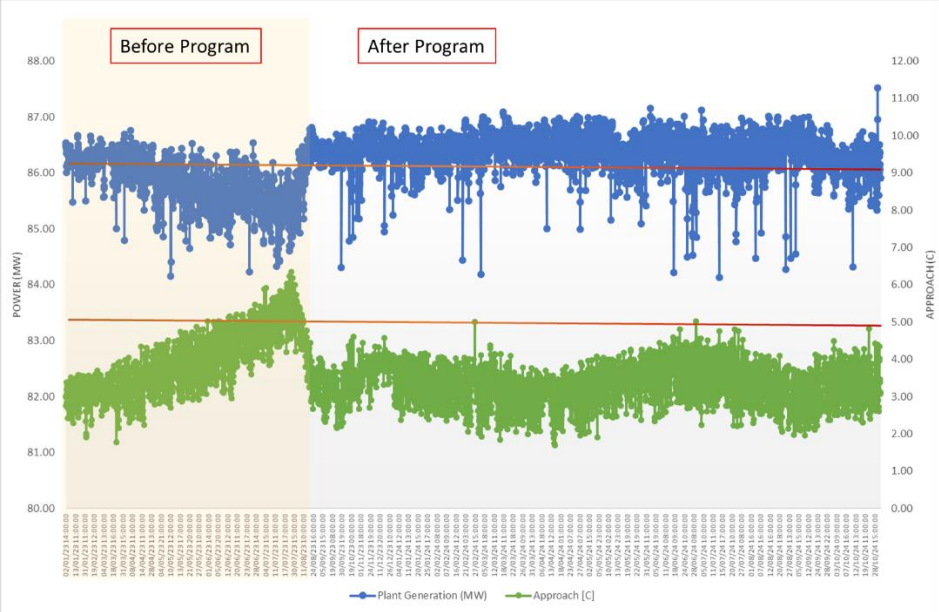


Figure 10. Before and after improvement program implemented for Plant generation

4.4 Economic Impact

Beyond the technical benefits, the integrated cooling tower improvement program delivered a substantial economic impact for Muara Laboh Geothermal Power Plant. The generation trend analysis between July 2023 to July 2024 shows a clear deviation between the actual generation achieved after the improvement program and the projected generation had no corrective actions been implemented.

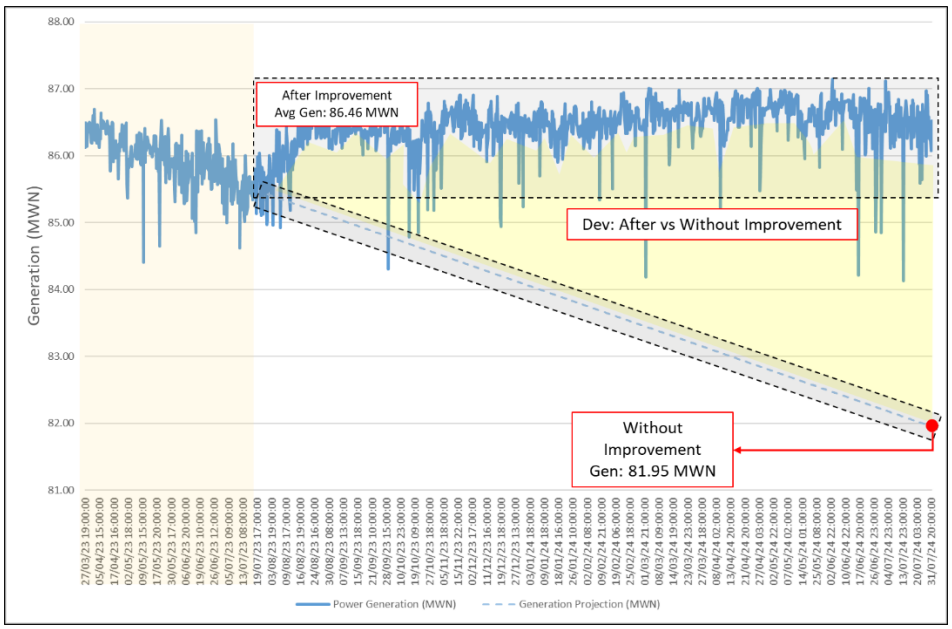


Figure 11. Actual vs. Projected Generation Trend (July 2023 – July 2024)

Without mechanical nozzle cleaning, rotation, and improved chemical dosing, cooling tower performance would have continued to deteriorate, reducing condenser vacuum and plant generation. Trendline projections indicate that generation would have gradually fallen to 81.95 MWN by July 2024 due to increasing CT approach and rising exhaust pressure.

In contrast, after completing nozzle cleaning and replacement on all eight CT cells and improving chemical dosing reliability, the plant maintained an average generation of 86.46 MWN throughout the evaluation period, avoiding operational derating and major energy loss. The difference between the two scenarios reflects the net generation loss prevented by timely improvements. Over one year, the projected shortfall would have reached 24,310.161 MWh, equivalent to approximately USD 3,160,320.95 in revenue loss.

This avoided loss demonstrates the importance of early detection, routine maintenance, and integrated mechanical–chemical strategies. The improvement program not only restored thermal performance but also protected substantial revenue and ensured long-term operational reliability.

5 CONCLUSION

The integrated cooling tower improvement program at Muara Laboh Geothermal Power Plant has demonstrated significant technical and economic benefits. The routine mechanical maintenance—particularly the cleaning and rotation of CT nozzles across all eight cells proved to be the most impactful action in restoring uniform water distribution and stabilizing cooling tower performance. This program enabled the CT approach to be maintained consistently below 5 °C, supporting a stable condenser vacuum and ensuring turbine exhaust pressure remained below 0.08 bara during full-load operation.

With these improvements, the plant successfully returned to and sustained its generation set point of 86.26 MWN, eliminating previous derating events caused by cooling system limitations. The prompt execution of these actions also prevented substantial economic losses. Without intervention, projected performance degradation would have reduced generation to 81.95 MWN by July 2024, resulting in an estimated loss of 24,310.161 MWh, equivalent to approximately USD 3.16 million. Timely maintenance therefore preserved both operational output and revenue.

Whereas not the direct driver of the 2023 recovery, the optimization of chemical treatment strengthened long-term system reliability. Improved dosing discipline, stable sulfur dispersant delivery, and better monitoring practices contributed to a gradual reduction in sulfate concentration and slower sulfur deposit growth on CT nozzles. These enhancements complement mechanical maintenance by minimizing fouling rates and extending the effective performance period between maintenance cycles.

Overall, this case study highlights the importance of combining corrective mechanical actions with consistent chemical management and comprehensive monitoring. The experience at Muara Laboh demonstrates that an integrated approach supported by disciplined execution and early anomaly detection is essential for maintaining cooling tower reliability, sustaining power plant performance, and preventing avoidable revenue loss in geothermal operations.

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