International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

The Cooling Tower Performance Analysis of Geothermal Power Plants in the Generation Business Unit

[1]*Budi Setiyana, [2]Naufal D. Kurniawan, [3]Muchammad

[1,2,3]Mechanical Engineering Department, Faculty of Engineering, Diponegoro University, Jl. Prof. H. Soedarto, SH, Tembalang-Semarang 50275, Indonesia

*Corresponding Author Email: bsetiyana@yahoo.com

***Abstract* - Cooling tower is an important part of the work cycle of geothermal power plants (PLTP). The cooling tower functions to cool the water flowing from the condenser and then releases the heat produced into the air. The type and components contained in the cooling tower affect the work and heat transfer from water to air. Air temperature, weather, and humidity are also important factors that determine the work and effectiveness of the cooling tower. This study aims to calculate and analyse the performance of the cooling tower of a Kamojang Geothermal Power Plant (PLTP), Indonesia based on available data in one day observation. The range and approach values containing air and water temperature data play a major role in the effectiveness of the cooling tower. The heat transfer that occurs includes gas and air which have a comparative amount so that the heat transfer process runs well which is contained in the L/G ratio equation. The one parameter or characteristic for Cooling Tower performance are given in the form of NTU (Number of Transfer Unit) data. It was found that the highest NTU value was at 9 PM to 10 PM and the lowest value was at 2 PM to 3 PM.**

Keywords: range, approach, effectivity, NTU.

I. INTRODUCTION

Kamojang Geothermal Power Plant (PLTP), Indonesia is the first geothermal power plant in Indonesia. In addition, Kamojang PLTP is also the first power plant in Southeast Asia that can create green energy hydrogen fuel from geothermal energy. In 1983, Kamojang PLTP began operating with unit 1 which can produce 30 MW of electricity. Not stopping with just one unit, Kamojang PLTP again inaugurated unit 2 and unit 3 in 1988. Unit 2 and unit 3 are each capable of producing 55 MW of electricity. Until now, Kamojang PLTP continues to operate 3 units in the PLTP for 24 hours non-stop to produce 140 MW of electricity.

The journey of a power plant is supported by components that work well, for example a cooling tower. A cooling tower is an important object in the power plant cycle to maintain the temperature of components in the power plant and efficiency in the process of creating electrical energy. The function of the cooling tower is to cool the hot water coming out of the condenser and the hot water coming out of the heat exchanger. Water from the condenser is flowed by the Main Cooling Water Pump or MCWP to the cooling tower to be cooled. Meanwhile, water from the heat exchanger is flowed by the primary pump. The water cooled in the cooling tower is useful for re-cooling the components and tools used in the power plant and helps the condenser to change the vapor phase to the water phase. In addition, the water from the cooling tower will be flowed into the injection well to keep the PLTP cycle running (Ruiz et al., 2022).

Water is cooled in the cooling tower through several processes. Steam from the turbine enters the condenser to be condensed or changed its phase to water. The condensed water has a hot temperature so it must be cooled so that it can be reused. Water from the condenser is channelled to the cooling tower using the main cooling water pump. The water that is channelled will enter the hot basin in the cooling tower. The hot basin is a temporary storage for hot water after being pumped by the MCWP to the cooling tower. Water will fall from the top of the cooling tower/hot basin to the bottom of the cooling tower/cold basin using the gravity process. While the water falls from the hot basin to the cold basin, the water will be cooled by the surrounding air sucked by a large fan located above the cooling tower. The cold incoming air will carry heat from the water so that the air coming out of the cooling tower is hot. Cold air enters the cooling tower through the air inlet in the form of louvres on the front and rear walls of the cooling tower (Bhattacharjee, Kumar and Chattoraj, 2023).

Basically, cooling towers have a working principle for the cooling process and heat release. The working principle of a cooling tower involves water and air in direct contact to exchange heat from one of them. The effect and result of the cooling tower's work is to change high-temperature water into low-temperature water. This is assisted by air from the surrounding environment where the air entering the cooling tower is at a low temperature while the air leaving the cooling tower is at a high temperature (Ma, Cai and Si, 2024).

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

Heat transfer in the cooling tower occurs by forced convection. Many factors affect the effectiveness of the work and heat transfer in the cooling tower. The type of component used to break the water or fill to the mass flow rate of water entering the cooling tower can be calculated. The more air flow or air flow rate that enters the cooling tower, the lower the temperature of the cold water. The ideal comparison of water and air in the cooling tower is also important to calculate because it affects the work of the cooling tower (Patil et al., 2018).

Cooling tower unit 2 of Kamojang Geothermal Power Plant works on the principle of mechanical draft with the type of induced draft axial fans. It is said to work on the principle of mechanical draft because there are motors and blades that function to suck air and remove hot air. Cooling tower unit 2 works on the principle of cross flow air flow. Cross flow air flow is where cold air enters the cooling tower through the air inlet or louvre on the front and rear walls of the cooling tower, the scheme of which is given in Figure 1.

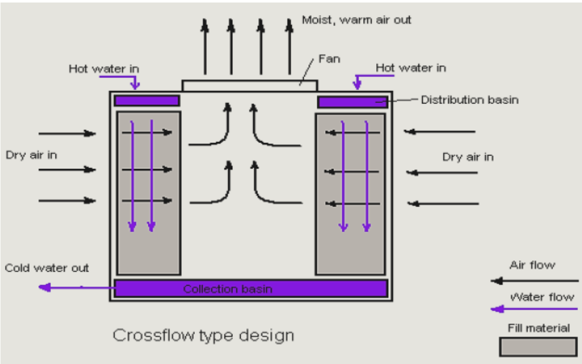

Figure 1: A schematic of air intake in Cooling Tower

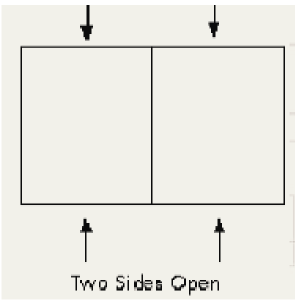

Figure 2: Intake air flow scheme

Air enters through the cooling tower wall and then the air turns into hot air which is discharged through the chimney located above. High temperature water flows from above through the side wall where the cold air enters. Therefore, the water resulting from the cooling of the cooling tower is located in the lower pool or cold basin. Because air enters through the two front and rear sides, this cooling tower unit 2 has two sides open type as the scheme is shown in Figure 2 (Primo, 2020).

II. MATERIAL AND METHOD

In relation to the evaluation of Cooling Tower performance, below are several parameters to be used in carrying out calculations related to Cooling Tower performance.

2.1 Range, Approach and Effectivity

The range in a cooling tower is the temperature difference between the hot water entering the cooling tower and the cold water leaving or completing the cooling process in the cooling tower. The range results in the cooling tower show how good the cooling process is. The greater the range value, the better the cooling process. The unit for range is °C. The equation for range is as follows (Primo, 2020),

Range (℃)= Hot Water Temperature (℃)– Cold Water Temperature (℃)

Approach is the difference between the water temperature after cooling and the wet bulb temperature. The smaller the value of the difference between cold water and wet bulb, the better the cooling tower performance. The equation for approach is as follows (Primo, 2020),

Approach (℃)=Cold Water Temperature (℃)–Wet Bulb Temperature (℃)

Effectiveness is the ratio between range and range plus approach. The closer to 100% the effectiveness, the better the performance of a cooling tower. The equation of effectiveness is as follows (Primo, 2020),

$$Effectivity = \frac{Range}{Approach + Range}$$

2.2 L/G Ratio Parameter

L/G ratio is the liquid to gas ratio or the comparison between water mass flow and air mass flow in the cooling tower operation process. The equation of L/G Ratio is as follows (Primo, 2020),

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2}$$

Where from the equation it should be known that:

- L/G = Liquid to gas ratio (kg/kg)
- h_2 = Enthalpy air-water vapor mixture at exhaust (kJ/kg)
- h_1 = Enthalpy air-water vapor mixture at inlet (kJ/kg)
- T_1 = Hot water temperature (°C)

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

- T_2 = Cold water temperature (℃)

2.3 Heat Load Total

It is the total heat load of the cooling tower's ability to remove heat into the air. The total head load equation can be written as follows:

$$Q = \dot{m}\, C\, \Delta T$$

Where from the equation it should be known that:

- Q = Head load total (kJ/s)
- ṁ = Mass flow rate water (m^3/s)
- C = Specific heat of incoming water(4,178 kJ/Kg℃)
- ΔT = Difference in temperature between incoming and outgoing water(℃)

2.4 NTU calculation using Merkel equation

Merkel equation was discovered by Dr. Merkel to calculate the rate of heat transfer between air and water. There are two methods for calculation, namely Tower Characteristic equation (KaV/L) or Number of Transfer Unit (NTU) equation. The KaV/L equation itself calculates evaporation and convection. Likewise, the NTU equation can calculate evaporation and convection through the flow and temperature entering the cooling tower. The Merkel equation can be written as follows (Shah and Tailor, 2015),

$$\frac{KaV}{L} = NTU = \int_{CWT}^{HWT} \frac{dT}{h_w - h_a} = Range\ x\ \left[\frac{1}{(h_w - h_a)}\right]/4$$

Where from the equation it should be known that:

- KaV/L = Tower characteristic
- K = Mass transfer coefficient (lb water/h ft^2)
- A = Tower Volume/Contact area
- V = Active cooling volume/Plan area
- L = Water rate (m^3/s)
- dT = Bulk water temperature (℃)
- H_w = Water enthalpy (Kj/Kg)
- H_a = Air enthalpy (Kj/Kg)
- HWT = Hot water temperature (℃)
- CWT = Cold water temperature (℃)

2.5 Data Collection

Data collection conducted on a particular day to analyze the performance of cooling tower unit 2 of PLTP Kamojang is by means of literature study and field study. The data obtained comes from the PLTP Kamojang control room operator, the results of interviews with the maintenance team, and the cooling tower manual. The available data will be processed with the equations that have been obtained through literature studies. The final result that will be obtained is the effectiveness or ineffectiveness of the cooling tower based on the real-time data obtained.

III. RESULTS AND DISCUSSION

Based on the description given above, below are the analysis results related to Cooling Tower performance.

3.1 Range, Approach and Effectiveness Calculation

The results of the calculation of Range, Approach and Effectiveness are given in table 1.

Table 1: Results Calculation of Range, Approach and Effectivity

Time	Range (°C)	Approach (°C)	Effectivity
00:00	16,6	11,3	0,594982
01:00	16,7	12,2	0,577855
02:00	16,7	12,1	0,579861
03:00	16,7	12,0	0,581882
04:00	16,7	13,1	0,560403
05:00	16,7	12,2	0,577855
06:00	16,7	12,3	0,575862
07:00	16,7	11,4	0,594306
08:00	16,5	12,3	0,572917
09:00	16,5	12,3	0,572917
10:00	16,5	12,3	0,572917
11:00	16,7	6,6	0,716738
12:00	16,7	6,6	0,716738
13:00	16,7	6,6	0,716738
14:00	16,6	6,9	0,706383
15:00	16,6	6,9	0,706383
16:00	16,8	11,0	0,604317
17:00	16,5	11,0	0,600000
18:00	16,5	11,4	0,591398
19:00	16,6	12,2	0,576389
20:00	16,4	12,2	0,573427
21:00	16,5	11,2	0,595668
22:00	16,5	11,2	0,595668
23:00	16,3	12,4	0,567944
00:00	16,4	12,6	0,565517

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

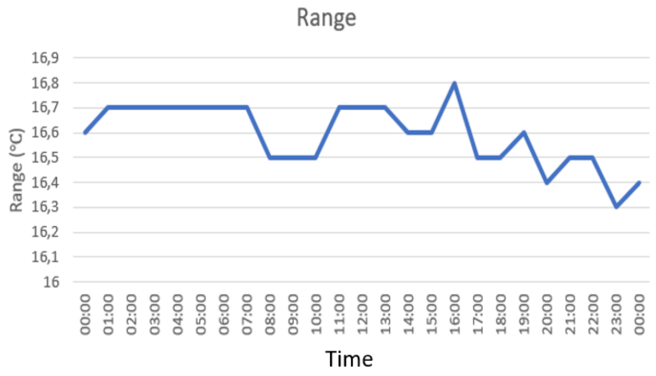

Figure 3: Range calculation result graph

Based on Figure 3, it can be seen that the largest range occurs at 4 PM at 16.8. This indicates that the best cooling tower works at 4 PM. While the lowest range occurs at 11 PM at 16.3. This indicates that the least good cooling tower works at 11 PM.

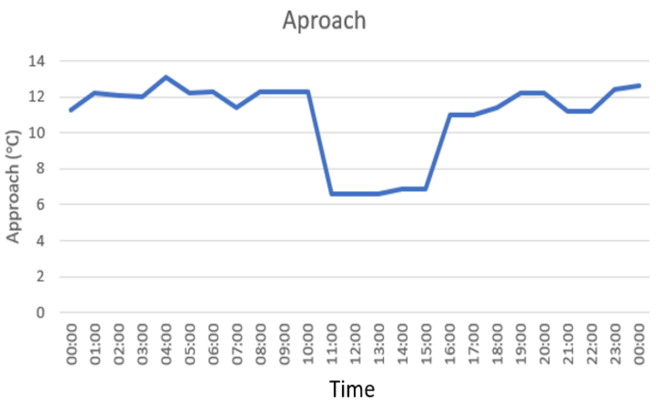

Figure 4: Approach calculation result graph

Based on the graph in Figure 4, it can be seen that the lowest approach value occurs at 11 AM at 6.6 to 1 PM. This indicates that the best cooling tower work is at 11 AM to 1 PM. While the highest approach occurs at 4 AM at 13.1. This indicates that the worst cooling tower work occurs at 4 AM.

Based on the graph in figure 5, it can be seen that the highest effectiveness value occurs at 11 AM at 0.71 to 1 PM. This indicates that the best cooling tower work is at 11 AM to 1 PM because the value is close to 1 or 100%. While the lowest effectiveness occurs at 4 AM at 0.560. This indicates that the least good cooling tower work occurs at 4 AM. The good or bad effectiveness of the cooling tower is influenced by the results of the range and approach.

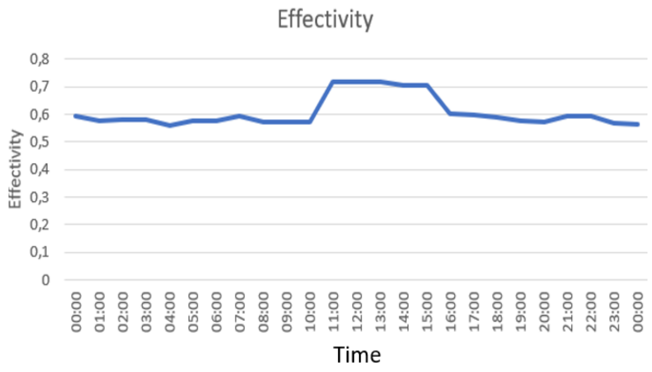

Figure 5: Effectiveness calculation result graph

3.2 Heat Load Calculation Results

Heat load is the total heat load of the cooling tower's ability to remove heat into the air. This heat load calculation is carried out on water so that it requires the specific heat value of water and the range value. The results of this heat load will determine the value of the amount of air needed for cooling the water given in table 2.

Table 2: Heat Load Calculation Results

Time	Q (kJ/S)	Q (kJ/Hr)
00:00	129982,4543	467936835
01:00	130765,4812	470755732
02:00	130765,4812	470755732
03:00	130765,4812	470755732
04:00	130765,4812	470755732
05:00	130765,4812	470755732
06:00	130765,4812	470755732
07:00	130765,4812	470755732
08:00	129199,4275	465117939
09:00	129199,4275	465117939
10:00	129199,4275	465117939
11:00	130765,4812	470755732
12:00	130765,4812	470755732
13:00	130765,4812	470755732
14:00	129982,4543	467936835
15:00	129982,4543	467936835
16:00	131548,5080	473574628
17:00	129199,4275	465117939
18:00	129199,4275	465117939
19:00	129982,4543	467936835
20:00	128416,4007	462299042
21:00	129199,4275	465117939
22:00	129199,4275	465117939
23:00	127633,3738	459480145
00:00	128416,4007	462299042

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

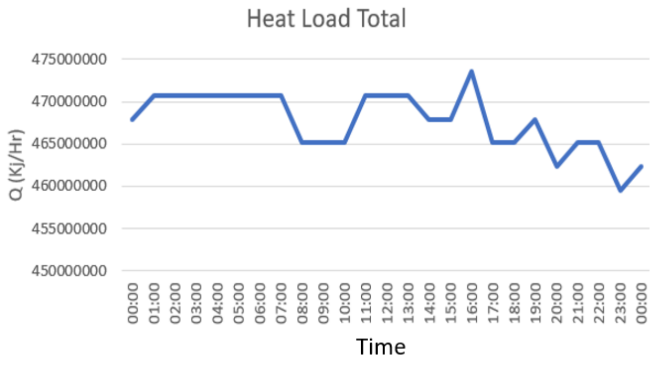

Figure 6: Total Heat Load calculation result graph

Based on data from table 2 and figure 6, it can be seen that the highest heat load value occurs at 4 PM, which is 473574628 kJ/hour.

3.3 L/G Ratio and Gas Calculation Results

L/G ratio is the comparison between water mass flow and air mass flow in the cooling tower operation process. The lower the L/G ratio, the better the performance of a cooling tower. The higher the L/G ratio, the worse the performance of a cooling tower. The L or liquid value is obtained through the calculation of the incoming air enthalpy, while the G or gas calculation is obtained through the range value. The calculation of the L/G ratio value is related to the heat load value to find the exact amount of water flowing and the amount of air used for the cooling process.

The G value in the L/G Ratio is the amount of air needed to cool per unit time. The G value can be found if you have obtained the total head load value of the water or the L value in the L/G ratio and the L/G ratio value. The results of the L/G Ration and Gas calculations are given in table 3.

Table 3: L/G Ratio and Gas Calculation Results

Time	L/G Ratio	G (m^3/hr)	G (m^3/s)
00:00	5,89759	22039,9259	6,122202
01:00	5,862275	22306,267	6,196185
02:00	6,071856	21536,3268	5,982313
03:00	6,071856	21536,3268	5,982313
04:00	6,071856	21536,3268	5,982313
05:00	6,071856	21536,3268	5,982313
06:00	5,862275	22306,2670	6,196185
07:00	5,862275	22306,2670	6,196185
08:00	5,933333	21775,1844	6,048662
09:00	5,933333	21775,1844	6,048662
10:00	5,933333	21775,1844	6,048662
11:00	4,407186	29670,9719	8,241937
12:00	4,407186	29670,9719	8,241937
13:00	4,407186	29670,9719	8,241937
14:00	4,704819	27627,5127	7,674309
15:00	4,704819	27627,5127	7,674309
16:00	5,613095	23436,0014	6,510000
17:00	5,715152	22606,4746	6,279576
18:00	5,715152	22606,4746	6,279576
19:00	5,897590	22039,9259	6,122202
20:00	5,969512	21512,0426	5,975567
21:00	6,145455	21023,5755	5,839882
22:00	6,145455	21023,5755	5,839882
23:00	6,220859	20517,0019	5,699167
00:00	6,182927	20769,5165	5,769310

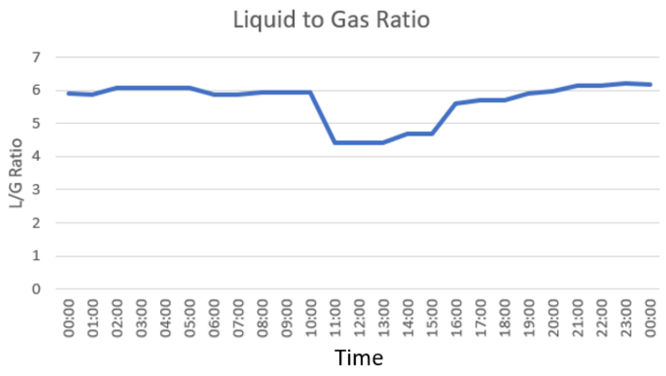

Figure 7: L/G Ratio calculation result graph

Based on Figure 7, it can be seen that the highest L/G ratio value occurs at 11 PM, which is 6.22. This indicates that the cooling tower is not working well at 11 PM because the L/G ratio value is the highest. While the lowest L/G ratio value occurs at 11 AM to 1 AM, which is 4.407. This indicates that the cooling tower is not working well at 11 PM. The effectiveness of the cooling tower is influenced by the results of the range and calculation of the incoming and outgoing air enthalpy.

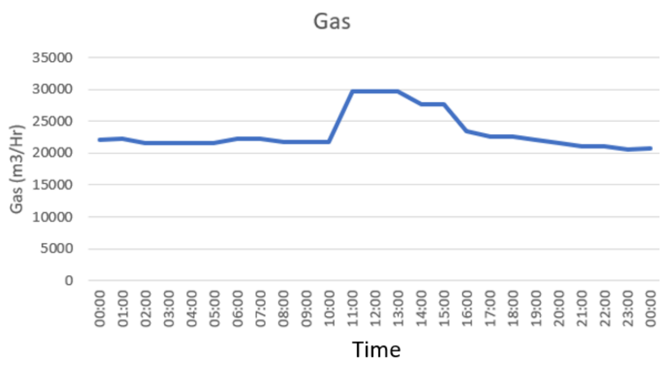

Figure 8: Gas Calculation Result Graph

Based on Figure 8, at 11 AM to 1 PM, it requires 29670 m^3/hr of air to cool. While at 11 PM, the lowest amount of air used for cooling was recorded, which was 20517 m^3/hr.

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 4, pp 317-323, April-2025

https://doi.org/10.47001/IRJIET/2025.904045

3.4 Number of Transfer Unit (NTU) Calculation

The NTU equation can calculate evaporation and convection through the flow and temperature entering the cooling tower, the data of which are given in table 4. The results of this calculation depend on the flow rate, enthalpy, hot water temperature, cold water temperature and others.

Table 4: NTU Calculation Results

Time	NTU
00:00	0,096669
01:00	0,097251
02:00	0,098212
03:00	0,099192
04:00	0,098212
05:00	0,097251
06:00	0,096309
07:00	0,095385
08:00	0,097036
09:00	0,097036
10:00	0,097036
11:00	0,093610
12:00	0,093610
13:00	0,093610
14:00	0,091329
15:00	0,091329
16:00	0,098800
17:00	0,099976
18:00	0,096087
19:00	0,097624
20:00	0,098369
21:00	0,108782
22:00	0,108782
23:00	0,107463
00:00	0,104672

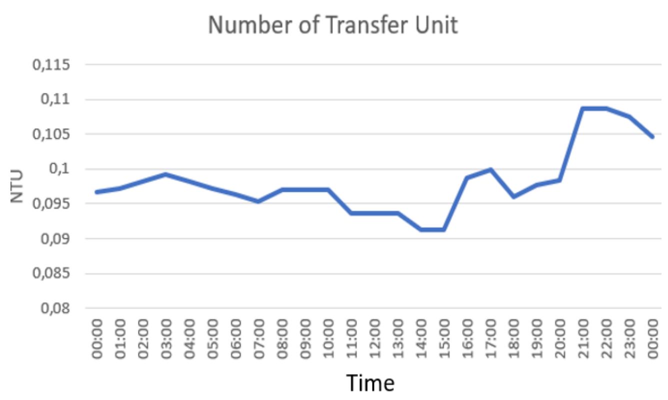

Figure 9: NTU calculation result graph

Based on the graph in Figure 9, it can be seen that the highest Number of Transfer Unit (NTU) value occurs at 9 PM to 10 PM at 0.108. While the lowest NTU value occurs at 2 PM to 3 PM at 0.091.

IV. CONCLUSION

From the calculations that have been carried out based on the available data and equations, several conclusions were obtained, including the following:

1. Heat transfer that occurs in the cooling tower is a type of heat transfer that occurs through forced convection between water and air. The heat transfer can be seen from the NTU equation which calculates evaporation and convection through the flow and temperature entering the cooling tower. The NTU calculation states that the highest NTU value occurs at 9 PM to 10 PM at 0.108. While the lowest NTU value occurs at 2 AM to 3 AM at 0.091.
2. Air temperature, water temperature, humidity, and weather greatly affect the performance and performance of the cooling tower. Range and approach are closely related to the effectiveness of the cooling tower. The greater the range value, the better the cooling process. The smaller the value of the difference between cold water and the wet bulb, the better the cooling tower performance. Therefore, if these two conditions are met, the effectiveness of the cooling tower will be very high as happened at 11 AM at 0.71 to 1 PM. The data indicates the best cooling tower performance because the value is close to 1 or 100%.
3. The amount of water and air needed to carry out the cooling process can be found in the L/G Ratio equation. The equation for liquid can be found through the heat load equation. While the equation for gas is obtained through the comparison results and heat load results.

REFERENCES

[1] Bhattacharjee, V., Kumar, P. and Chattoraj, C., 2023. Optimal design of forced-draft counter-flow evaporative-cooling towers through single and multi-objective optimizations using oppositional chaotic artificial hummingbird algorithm', 46(October), pp. 1–22.

[2] Li, Y. et al., 2024. Numerical study on heat and mass transfer performance of a natural draft wet cooling tower based on baffle optimization. Applied Thermal Engineering. Available at: https://doi.org/10.1016/j.applthermaleng.2024.122738.

[3] Ma, H., Cai, L. and Si, F., 2024. Thermo-economic analysis of the impact of the interaction between two neighboring dry cooling towers on power generation of

ISSN (online): 2581-3048
Volume 9, Issue 4, pp 317-323, April-2025
https://doi.org/10.47001/IRJIET/2025.904045

dual thermal power units and the energy-efficient operation strategy, 240(2).

[4] Patil, M.M. et al., 2018. Design and Analysis of Cooling Tower.

[5] Perpindahan, A. et al., 2020. Analysis of Heat and Mass Transfer on Cooling Tower Fill, 14, pp. 25–30.

[6] Primo, I.J., 2020. Cooling Towers - Basic Calculations, 374.

[7] Ruiz, J. et al., 2022. Thermal performance and emissions analysis of a new cooling tower prototype. Applied Thermal Engineering, 206. Available at: https://doi.org/10.1016/j.applthermaleng.2022.118065.

[8] Shah, P. and Tailor, N., 2015. Ijaret Merkel S Method for Designing Induced Draft Cooling Tower, pp. 70–77.

Citation of this Article:

Budi Setiyana, Naufal D. Kurniawan, & Muchammad. (2025). The Cooling Tower Performance Analysis of Geothermal Power Plants in the Generation Business Unit. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 9(4), 317-323. Article DOI https://doi.org/10.47001/IRJIET/2025.904045

****