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Performance Analysis of *Counter Flow Cooling Towers* Based on Actual Performance Data

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***Abstract**.*
Cooling towers are widely used in various industrial applications for water cooling systems. In these towers, water is cooled by air, and the heat released from the water to the air consists of both sensible and latent heat. The efficiency of this heat transfer significantly impacts the performance of the cooling tower. ***Objective:*** *This study aims to determine the effectiveness and mass flow rate of water in a cooling tower, focusing on the relationship between water temperature, flow rates, and overall cooling tower performance.* ***Method****: The analysis includes measurement of the water temperature (48.176 °C), mass flow rate (175.235 kg/s), and the wet bulb temperature (16.988 °C) in the cooling tower. These parameters are analyzed to assess the cooling tower's performance in terms of its heat transfer efficiency.* ***Results****: The cooling tower's performance analysis shows an effectiveness of 59.36%. The mass flow rate of water is 175.235 kg/s, and the hot water flow rate is 9373.32 kg/s. The data indicate that the improved water flow and air flow have a positive impact on the heat transfer rate.* ***Novelty****: This study highlights the critical role of maintenance and the optimization of flow rates and cooling tower components in enhancing the heat transfer efficiency. It offers valuable insights into the relationship between operational parameters and cooling tower performance.* ***Implications****: The findings suggest that proper maintenance and improvements to water and air flow can significantly enhance cooling tower efficiency, leading to better heat transfer and overall system performance. This has important implications for industrial applications that rely on cooling towers for effective water cooling systems.*

Keywords ~ *Counterflow Cooling Tower, Range and Approach, Thermal Effectiveness*

INTRODUCTION

In general, *cooling towers* can be categorized as evaporative coolers used to cool water or other working media to a temperature close to the wet bulb temperature of the surrounding air. The main purpose of *cooling towers* is to remove heat absorbed by the circulation of cooling water used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food factories, semiconductor factories, and other industrial facilities. If a factory is not equipped with *a cooling tower* and only uses a

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single-use cooling water circulation system, the used cooling water will experience a temperature increase and then be discharged into the sea, lake, or river. The discharge of this warm water can increase the temperature of the river or lake, thereby damaging the local ecosystem. *Cooling towers* can be used to dissipate heat into the atmosphere as a substitute for wind and air diffusion, which spreads heat over a wider area.

The design of *cooling towers* involves several fields of study, including thermodynamics and fluid mechanics, which can be applied to the manufacture *of cooling towers* in terms of both their working processes and phase changes. The purpose of this study is to analyze the performance of *a counterflow cooling tower* using a film filler. *Counterflow* is the flow of air through the fill material parallel to the water flow in the opposite direction. The approach taken to design *the cooling tower* test bed is based on thermodynamics and fluid mechanics concepts, because the performance of this *cooling tower* involves the theory of fluid temperature change due to heat transfer from fluids (water and air) that are in direct contact with air through forced convection using a fan. The target of this research is to analyze the performance of *a counter flow cooling tower* to ensure that it works properly. The cooling process in this design can produce a temperature close to the wet bulb. (Reyhan, Nuriskasari, & Saputra, 2024)

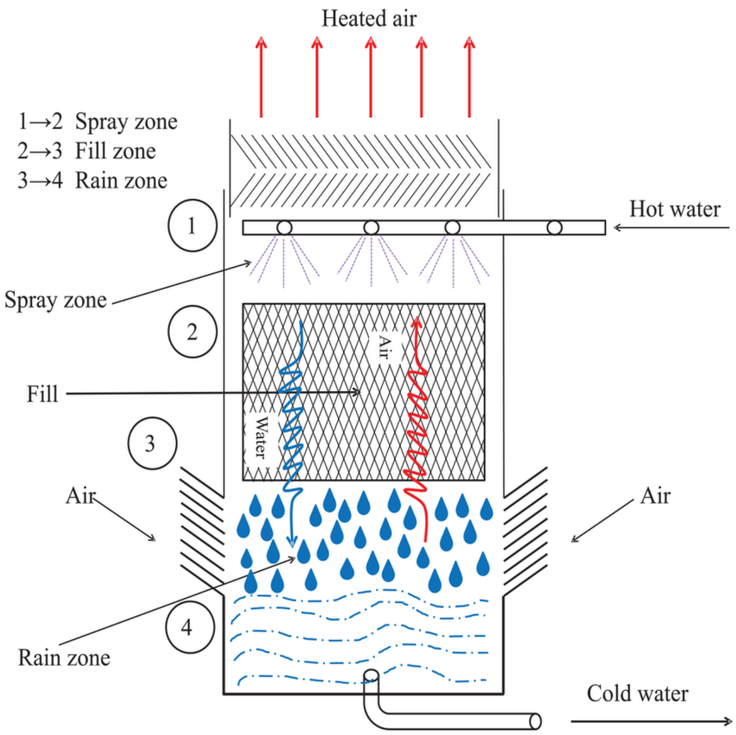

Figure 1. Illustration of *Cooling Tower* Construction

(Guo, Qi, Sun, & Guo, 2019)

LITERATURE REVIEWS

A cooling tower is defined as a heat exchanger that cools water through direct contact with air, causing a small amount of water to evaporate. *Cooling towers* that work in air cooling systems typically use centrifugal pumps to move water through the tower. *Cooling tower* performance is usually expressed in *range* and *approach*. (Rahman & Mursadin, 2022)

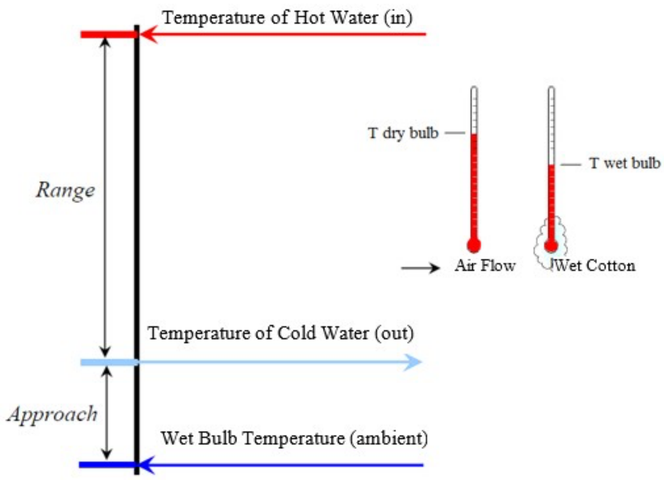

Figure 2. *Range* and Approach Temperature in *a Cooling Tower* *(Rahman & Mursadin, 2022)*

Cooling towers use evaporation, whereby some of the water is evaporated into the moving air flow and then released into the atmosphere (Effendi and Wirza, 2013). Equipment Effectiveness (OEE) measurement uses three ratios as a basis: availability ratio, performance ratio, and quality ratio (Muhsin, 2016). With this knowledge, companies can also make improvements or prevent possible damage in order to increase productivity (Ningrum and Muhsin, 2016). Cooling tower performance is evaluated to discuss the approach and range of operation at design values, identify areas of energy waste, and also as a means of improvement (Handoyo, 2015). With an adequate and continuous supply of cool (cold) water, the cooling tower as a heat exchanger can operate according to specifications and expected conditions. Additionally, the costs incurred will be more effective and energy consumption will be more efficient (Yulianto and Urbiantoro, 2013). Cooling towers are stored in enclosed rooms to avoid extreme fluctuations in temperature and humidity (Wibisono, 2005).

METHODS

The data collected is from the control room during operation. Digital tools are used to obtain more accurate and precise figures. Specific *cooling tower* design data is used as a reference and *basic data* for calculating *cooling tower* performance. With the design data, we can determine the limitations in using and operating *cooling towers* at a power plant. The following is a table of specific design data used in accordance with the initial *project* specifications for manufacture and construction.

Table 1. *Cooling Tower* Specification Data

No	Parameter	Design	Unit
1	Circulating Water Flow Rate	41726.5	GPM
		263.25	m/s
		348,221.55	lb/min
2	Inlet Water Temperature (T-Hot Water)	110.66	°F
		43.7	°C
3	Water outlet temperature (T-Cold Water)	77.9	°F
		25.5	°C
4	Wet bulb temperature Inlet (Twb Inlet)	59	°F
		15	°C
5	Wet bulb temperature Exit (Twb Exit)	92.12	°F
		33.4	°C
6	Dry Bulb Inlet Temperature (Tdb Inlet)	71.6	°F
		22	°C
7	Relative Humidity	50	%
8	Motor rotation	1500	RPM
		127.85	KW
9	Cooling tower height	5741	ft
		1750	M
10	Water Flow	641	m^3/hour
11	Heat Load	198748	KW
12	Cooling Tower Characteristics (Ka V/L)	1342	-
13	L/G Ratio	11377	-
14	Number of Fans	4	Fruit
15	$KaV/L = 1.45*(L/G)_{-0.6}$		

RESULTS & DISCUSSION

The following table shows performance based on data for Circulating Water Temperature (Hot Water) and *Cooling Tower* Outlet Water Temperature (Cold Water). The hot water temperature (T-Hot water) data was taken from the condenser outlet temperature, which then enters the *cooling tower*. Meanwhile, the cold water temperature data (T-Cold water) was taken from the water leaving *the cooling tower*. In addition, there is also data on *the Cooling Tower* Inlet Water Flow Rate (Q in) and Wet Bulb Temperature Readings (*Twet bulb*) by comparing the average Twet bulb with the design conditions.

Table 2. Actual *Cooling Tower* Performance Data

Time	T water Ct in °C	T water Ct out °C	Flow Rate In *cooling tower* (m^3/s)	Twet Bulb °C
00.00	48,3	31	9.35	15,55
01.00	48,2	30,7	9.14	16,3
02.00	48,11	30,7	9.32	16,6
03.00	47,4	30,5	9.32	16,1
04.00	47,7	30,6	9.40	15,7
05.00	48,2	30,7	9.31	16,3
06.00	47,8	30,6	9.31	16,7
07.00	47,9	30,6	9.45	17,1
08.00	48	30,9	9.20	17
09.00	50,4	29,6	9.50	17
10.00	49,6	29,5	9.32	17
11.00	49,4	29,5	9.38	17
12.00	50	29,7	9.32	17,5
13.00	49,3	28,2	9.26	18,1
14.00	49,5	29,4	9.44	18,1
15.00	49,1	29,1	9.44	18
16.00	48,9	29,2	9.50	17,9
17.00	49	29,1	9.50	17,8
18.00	48,9	28,7	8.96	17,6
19.00	47,8	28,4	9.38	16,5
20.00	48	28,4	9.30	16,7
21.00	48,2	28,6	9.50	16,9
22.00	42	28,6	9.50	16,8
23.00	46	29,2	9.50	17
24.00	47	30,1	9.50	17,2
Avg	48,176	29,66	234.1	16,988

Mathematical Calculation Analysis

The working principle of *a cooling tower* is based on heat release and heat transfer. Heat transfer in *a cooling tower* occurs from water to air. *Cooling towers* use evaporation, whereby some of the water is evaporated into the moving air flow and then released into the atmosphere, significantly cooling the remaining water.

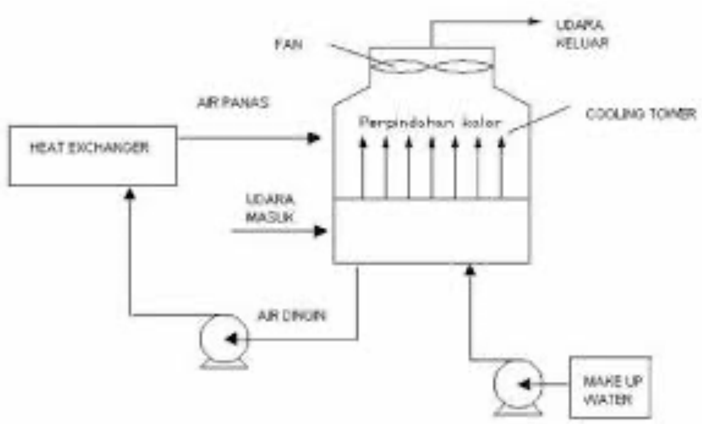

Figure 3. Cooling Tower Schematic Diagram

The working principle of *a cooling tower* can be seen in the figure above. Water from the tank/basin is pumped to *the heater* to be heated and then flows to *the cooling tower*. The hot water that comes out comes into direct contact with the surrounding air that is forced to move due to the influence of *a fan or blower* installed at the top of *the cooling tower*, then flows down to the filler material. This system is highly effective in the water cooling process because the condensation temperature is very low, approaching the *wet bulb* temperature of the air. The water that has undergone a temperature reduction is collected in a basin. A *make-up water* valve is also installed in *the cooling tower* to add cooling water capacity if water loss occurs during the *evaporative cooling* process. [2]

Table 3. Actual *Cooling Tower* Data

No	Parameter	Quantity
1	Twb	16,988 °C
2	Tdb	22 °C
3	T out	29.66 °C
4	T in	48.176 °C
5	Water Flow	641,m^3/ hour
6	Air mass	35 °C
7	Air mass	58 °C

1. Range = Inlet water temperature (T in) – Outlet water temperature (T out)
   = 48.176 °C - 29.66 °C
   = 18.516 °C
2. Approach = Outlet water temperature (T out) – Wet bulb temperature (Twb)
   = 29.66 °C – 16.988 °C
   = 12.672 °C

3. Efficiency = $\frac{Range}{Approach+Range} \times 100\%$

   $= \frac{18.516\ ℃}{12.672\ ℃+18.516\ ℃} \times 100\%$

   = 59.36%

4. Water mass flow rate

   L = Q water× p water 58 °C

   The density of water at 58 °C (Table A.3, Heat Transfer, John H. Lienhard) is 984.16 kg/m^3

   = 641m^3/ hour× 984.16 kg/m^3

   = 630.846 kg/hour

   = 175.235 kg/s

The performance of *the cooling tower* based on data collection and testing results shows that the values are still quite good. This is indicated, among other things, by:

- The difference in water temperature between the inlet and outlet of *the cooling tower* compared to the design specification data is not too large (18.516 °C). This difference may be caused by the difference in wet bulb temperature (Twet bulb) during the test compared to the design conditions. The range indicates how much the water temperature can decrease through the cooling process. The larger the range, the greater the temperature decrease that occurs in the cooling tower.
- The performance *of the cooling tower* is simulated through mathematical calculations. From the simulation results, the performance can be analyzed and the efficiency value *of the cooling tower* can be determined based on the effects of temperature, the flow rate of water entering the *cooling tower*, and the flow rate of air entering the *cooling tower* to improve its performance.
- An effectiveness of 59.36% indicates that the cooling tower only achieves about 59% of the ideal temperature reduction potential that can be achieved. In practice, this value indicates that there is potential to improve cooling efficiency to be more effective and perform well.
- The water mass flow rate value of 175.235 kg/s means that the water mass flow rate in *the cooling tower* is ineffective. Increasing the water mass flow rate in the cooling tower does not always lead to a greater temperature reduction. In practice,

cooling effectiveness depends more on the contact time and surface area available for heat exchange. Increasing the water flow rate too high can actually reduce cooling effectiveness, due to the reduced time for water to release heat through evaporation and the increased thermal load that the system must overcome.

- In the performance data table, the actual water temperature value in *the Cooling Tower* (Ct in) is 48.176 °C and the specification data value is 43.7 °C. The difference between the actual value and the specification data value is very small, so the temperature value is considered normal.
- In the performance data table, the hot water flow rate in *the Cooling Tower* (Q in) is 9373.32 kg/s and the specification data value is 263253.3 kg/s. The difference between the actual value and the specification data value is very large. If the flow rate is higher, it will take longer to cool the water.
- Wet bulb temperature describes a more realistic air temperature for calculating the evaporation process because it is influenced by air humidity. The smaller the approach value, the closer the outlet water temperature is to the wet bulb temperature, which indicates higher efficiency in the evaporation process. In the performance data table, the actual wet bulb temperature (WBT) value for *the cooling tower* is 16.988 °C, and the specification data value is 15 °C. The difference between the actual value and the specification data value is very small, so the wet bulb temperature value is considered normal.

CONCLUSION

From the results of data collection and processing in this study, it can be concluded that the cooling tower that was built can be used to determine an effectiveness value of 59.36%, meaning that the *cooling tower* machine is still effective and performing well. The water mass flow rate is 175.235 kg/s, which means that the water mass flow rate in *the cooling tower* is ineffective because the higher the water mass flow rate, the lower the temperature in *the cooling tower*. The cooling capacity of the cooling tower that was made has not yet reached the ideal cooling capacity, and the water flow rate needs to be increased so that the ratio is within the cooling tower standard. If the water flow rate is increased, the heater power must also be increased so that the water heats up faster.

There are several differences between actual data and design specifications, such as higher inlet water temperature and lower water flow rate than expected in the design. This can affect cooling performance because hotter water will increase the thermal load on the system, while a lower flow rate limits cooling capacity. To improve the cooling tower's performance, it is necessary to adjust the water flow rate to be more optimal and in line with the design capacity, as well as improve air distribution to extend the contact time between water and air. This will enhance the evaporation process and, in turn, improve cooling effectiveness. Overall, although the cooling tower performs reasonably well, there is potential to improve cooling efficiency by adjusting certain operational factors, such as water flow rate and air distribution.

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