



# Performance Evaluation of Efficiency and Effectiveness of a Cooling Tower in a Fertilizer Production Plant

Okari, J. A., Le-ol, A. K., Oparadike, F.E.

Department of Mechanical Engineering, Rivers State University, Port-Harcourt, Nigeria

Received: 20.10.2025 | Accepted: 29.10.2025 | Published: 01.11.2025

\*Corresponding Author: Okari, J. A.

DOI: [10.5281/zenodo.17500864](https://doi.org/10.5281/zenodo.17500864)

## Abstract

## Original Research Article

This study evaluates the efficiency and effectiveness of Cooling Tower at Indorama Petrochemicals, Port-Harcourt. Cooling towers are known to have high energy losses from heat loss, evaporation losses and from other sections of tower, leading to water source limitation, the variation in the climatic conditions, particularly, the relative humidity of the ambient air and its cooling tower or its components deterioration. Thus, the efficiency of the cooling tower varies from time to time, and this affects the quantum of heat energy dissipation in production processes because of insufficient air flow, irregular cleaning and maintenance of the inner part of the cooling tower, decreased water treatment, decreased fan operation system, poor fill media materials and the geometrical arrangement of the cooling tower lead to many problems such as reduced efficiency, low production output, substandard condition and quality, and high maintenance cost are the major concern of this research work as it affects the efficiency, productivity, and overall effectiveness of the petrochemical plant. The heating load, influenced by water temperatures, rises from 72.73 MW at an inlet temperature of 36°C to 108.08 MW at 52°C, emphasizing the substantial impact of inlet water temperature on thermal load. Additionally, the evaporation loss, influenced by water volume flow-rate, exhibited a predictable rise with increased flow-rates. For instance, at a flow-rate of 6950 m<sup>3</sup>/h, evaporation loss is 95.70 m<sup>3</sup>/h, escalating to 142.21m<sup>3</sup>/h at 7150 m<sup>3</sup>/h, highlighting the role of water-air contact in promoting evaporation. The positive correlation between water volume flow-rate and pumping power is evident, as an increase from 1.93 m<sup>3</sup>/s to 1.99 m<sup>3</sup>/s results in a rise in pumping power from 284.08 kW to 292.26 kW. The study further revealed an inverse relationship between the cycle of concentration and both blow-down and makeup water rates. As the cycle of concentration increased from 2 to 10, blow-down rate decreases from 95.70 m<sup>3</sup>/h to 15.80 m<sup>3</sup>/h, suggesting water conservation benefits. Cooling efficiency, influenced by inlet water temperature and liquid to gas ratio, improves from 65% to 71% as temperatures rise from 36°C to 52°C and the ratio decreases from 1.4 to 0.97. These findings offer valuable insights into optimizing cooling tower operations, emphasizing resource conservation and sustainability. In conclusion, the study provides a nuanced understanding of the cooling tower performance, offering practical implications for operational enhancements and resource efficiency.

**Keywords:** Cooling Tower, Evaluation, Efficiency, Effectiveness, Indorama, Petrochemicals, Temperature

Copyright © 2025 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).

## INTRODUCTION

Cooling towers are integral part of utility section, sometimes they are the most important section of manufacturing processes. Most

petrochemical manufacturing processes require chemical reaction between elements as to form a required composite material or the decomposition of chemical bonds in compounds for a desired product formation (production). During these processes, a



quantum of heat is generated or required for the production processes at well-defined chemical and thermodynamic conditions as is the case of Indorama Petrochemicals Company as shown in Plate 1. In order to achieve the expected production processes these conditions are being controlled or regulated by means of other industrial methods or appliances. Thus, the phenomenon of heat control, heating process and temperature regulation in production process becomes a concern to the engineers and manufacturers in the industries (Dhruvit & Chetan, 2016). Such large amount of heat generated by these industrial processes and machines therefore requires

continuous dissipation and temperature management for efficient operations. This is achieved through a heat exchanger process which forms the basis of the cooling tower technology. Hence, the advent of cooling water and cooling tower circulation system for effective water/temperature management in the industries become paramount and significant. In the cooling tower system, the warm water is sprayed into the tower by nozzles within the internal zone opposite to ambient air stream moving upward near the top and allowed to fall through a packing of slats which break up the stream and provide a large, wetted surface to facilitate evaporation.



**Plate 1: Indorama Eleme Petrochemical Plant, (Indorama Eleme Petrochemical Company Limited, 2022)**

Cooling towers require distribution or sprinkling water over a heat transfer surface across or through which a stream of air passes. As a result, the water droplets are incorporated in air streams. This is called a drift and it is independent of water evaporation loss. Drift eliminators are used in cooling towers in order to reduce the water loss from the system. Drift eliminators change the direction of the airflow as it passes through the eliminator so that most of the entrapped droplets are separated from the air stream and return to the tank. The cooling towers also normally contain a wetted medium called fill to control evaporation by providing a large surface area. Due to the presence of the drift eliminator and fills, the cooling towers thermal performance is dependent on the thermal properties and performances of these components (Kiran et al., 2017; Yagnesh et al.,

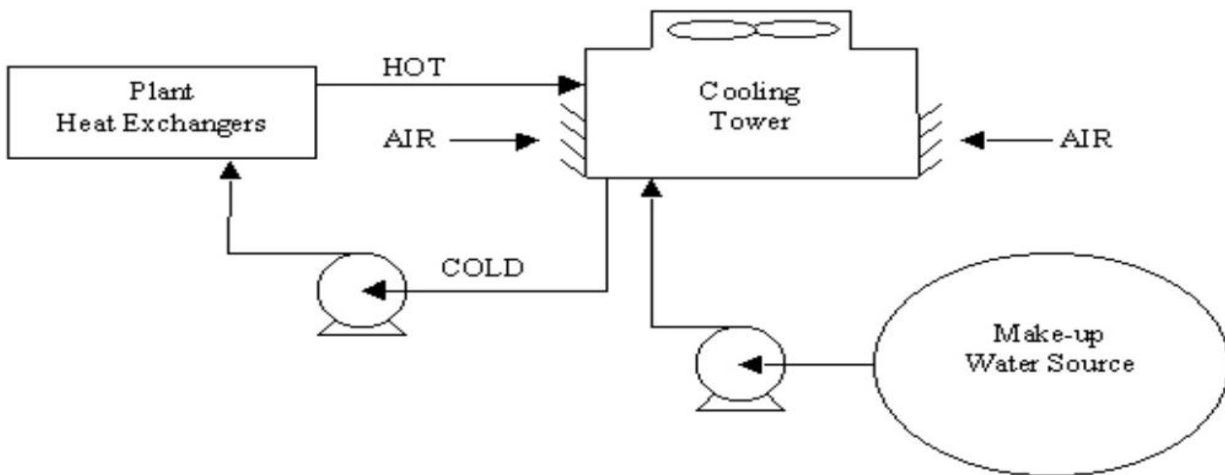
2017).

Cooling towers can be classified by the type of heat transfer; the type of draft and location of the draft, relative to the heat transfer medium; the relative direction of air and water contact and the type of water distribution system (Mustafa et al., 2020). Originally, cooling towers were constructed primarily with wood, including the frame, casing, louvers, fill and cold-water basin (Satish, 2016). Sometimes the cold-water basin was made of concrete. Today, manufacturers use a variety of materials to construct cooling towers. Materials are chosen to enhance performance, corrosion resistance, reduce maintenance, and promote reliability and long service life (Vishnu & Reji, 2018). Galvanized steel, various grades of stainless

steel, glass fiber, and concrete are widely used in tower construction, as well as aluminum and plastics for some components (Pushpa et al., 2014). Towers can be either factory built or field erected - for example concrete towers are only field erected. Many towers are constructed so that they can be grouped together to achieve the desired capacity. Thus, many cooling towers are assemblies of two or

more individual cooling towers or cells. The number of cells they have, e.g., Eight-cell tower, often refers to such towers. To fill-up again water lost to evaporation the make-up water source is used. Hot water from heat exchangers is received by cooling tower. The water departs from the cooling tower which is return to the heat exchangers or to other sections for additional cooling.

Figure 1 represents the prototypical closed loop cooling tower system.



**Figure 1: Cooling Tower**  
(Klopper & Kroger, 2003)

Multiple-cell towers can be lineal, square, or round depending upon the shape of the individual cells and whether the air inlets are located on the sides or bottoms of the cells. Natural draft cooling towers use very huge chimneys, which is made up of concrete, to placed air through the channel. Due to the huge size of these towers, they are basically used for water flow rates higher than 45,000m<sup>3</sup>/h., while a mechanical draft tower uses large fans (Piyush et al., 2016). The large fan is sucking or force air across circulated water. To increase the contact time between the water and the air and to maximize heat transfer between water and air, the water drops down above fill surfaces (which is usually made of plastic or wood) is used. Cooling speed of Mechanical draft towers rely upon their fan diameter and speed of

operation Chan (2015) studied cooling tower performance analysis and visible air plume abatement in buildings situated in temperate climate zone. A sophisticated mathematical model, the Poppe Approach was studied and developed a web-based calculator based on the theory. A real size mechanical cooling tower in China was constructed to carry out a validation test and showed to be very accurate and more accurate than the industrial approach, the Merkel Approach. Based on this validated Popped Approach, an artificial environmental chamber was designed and constructed in China, and tests were conducted to identify the visible plume formation. CFD simulations were conducted to compare with the experimental results to validate the CFD simulation

itself. Meanwhile, an alternative visible plume abatement approach was developed, the water shedding approach. The water shedding approach was designed to reduce the hour of visible plume occurrence and to reduce the severity of visible plume. A building load of a commercial building was used to carry out visible plume abatement evaluation with the water shedding approach. With a Hong Kong climatic data, hours of visible plume would reduce by 38.2% and severity of visible plume was reduced by 40-60%. With the validated CFD simulation and the water shedding approach, CFD simulation was conducted in an urban city environment and with cooling tower operating with and without the use of water shedding approach. It was found that CFD simulation results showed that there was a maximum in temperature of 0.33°C and maximum moisture content of 0.0003kg/kg. In order to bridge the gap between academic and industry, a web-based platform was created that stored information related to cooling tower, as well as the fast calculators (the Popp Approach calculator and the visible plume abatement calculator) developed during this research topic. His study recommends that this web-based platform would provide engineer a user-friendly tool to carry out evaluation in cooling tower plant design and visible plume abatement evaluation.

Dastia et al. (2020) conducted an experiment on wet refrigeration towers using dynamic ecological approach to evaluate the water saving potential for recycling water evaporation. The result shows that water losses at the fill media unit, control a maximum of 440m<sup>3</sup>/h to a minimum of 108m<sup>3</sup>/h level to promote environmental sustainability. The study addressed the problems found through an environmental review of current and future cooling systems, the technological, economic, and environmental implications, with possible technical and non-technical solutions. Considering the current water crisis around the world, it was essential to expand the functions of these wet refrigeration towers to decrease their water consumption with maintaining their performance, as it has a great potential to recycle water evaporation. Experimental

data was measured, and dynamic Eco approaches were performed to evaluate the water saving potential. The result showed that water losses at one unit control from maximum 440m<sup>3</sup>/h level to minimum 108 m<sup>3</sup>/h level to promote environment sustainability.

Dhruvit and Chetan (2016) analysed cooling tower performance and determining energy saving opportunities through economizer operation: a review. The chilled water system analysis tool (CWSAT) software was developed as a primary screening tool for energy evaluation for chilled water systems. This tool quantified the energy usage of the various chilled water systems and typical measures that can be applied to these systems to conserve energy. The tool required minimum number of inputs to analyse the component-wise energy consumption and incurred overall cost. In their study, a new model to predict cooling tower performance was created to give a more accurate picture of the various energy conservation measures that were available for cooling towers. The weaknesses of the current model were demonstrated, and prediction capabilities of the new model analysed and validated. Further the economic feasibility of having additional cooling tower capacity to allow for economizer cooling, considering reduced tower capacity at lower temperatures was investigated.

According to Pushpa et al. (2014) in the performance evaluation of cooling tower in thermal power plant-a case study of RTPS, Karnataka. In their study, it was showed that by minimizing the size of water droplet, the performance of natural draft cooling tower can be enhanced. The study of sensitivity analysis was done which shows the dependency of parameters like air temperature, water temperature, relative humidity and rate of heat loss. Further, efficiency was also checked by using power generation data.

Rohan and Naveen (2019) studied the design and performance analysis of cross flow & force draft cooling towers. In their study an energy and space efficient cooling tower was designed. Models were imported into Ansys fluent where meshing and analysis was carried out. Air inlet pipe was varied

across different angles. Based on the water outlet temperature, the effectiveness of the different models was studied and analysed. In their study they maintained that tower is a substantially used in buildings, but also significantly contributes to internal heat gains. They asserted that recent advancements have allowed for higher efficiency building retrofits to be installed, yet we cannot neglect the fact that the current working practices are demanding. During the designing stage the Contractors or Consultants often rely on technological benchmarks to predict energy consumption, power demands and various other parameters such as temperature, Air quality etc.

Mustafa et al. (2020) conducted an evaluation of thermal performance for natural and forced draft wet cooling tower. Their study presented an experimental and numerical investigation of the thermal performance of natural draft wet cooling tower (NDWCT). The experimental investigation was carried out under natural draft condition and forced draft condition created by an axial fan. The operational parameters considered in their study are the thickness of the fill (10 and 20 cm), inlet water temperature (40, 45, and 50°C) and inlet water volume flow rate (5.68, 7.75, and 9.46 L/min). The experimental results showed that the thermal performance was improved when the fans are used with the NDWCT.

The temperature difference between inlet and outlet and effectiveness increases by 35% and 37.2% respectively at fill thickness of 20 cm and water volume flow rate of 11.35 L/min. The temperature distribution of the air and the relative humidity were numerically simulated for both cases of natural and forced draft by employing the commercial CFD software Ansys Fluent 15. The experimental and numerical results were validated with results from a previous work and showed a good agreement. The experimental results showed that the effectiveness increase by 22% and 30% for NDWCT and FDWCT respectively when in case of fill thickness 20 cm.

Shivam and Arvind (2018) carried out thermal performance analysis and design modification of

natural draft wet cooling tower. Their study dealt with the performance study and analysis of induced draft cooling tower, which is one of the deciding factors used for increasing the power plant efficiency also modelling and analysis of flow using software. Their study aimed to address the modeling of cooling tower in solid works software and to measure performance of cooling tower to achieve more cooling efficiency. The performance of the induced draft cooling tower was evaluated, and the structural analysis was carried out in solid works simulation tool by varying the materials namely galvanized steel, stainless steel, concrete, and balsa wood.

According to Ovat and Anyandi (2020), a model laboratory cooling tower was designed and produced using locally available materials and was used in conjunction with a residential size water heater to simulate the industrial process heat load. The aim of their research was to evaluate the performance of the cooling tower produced locally to determine the influences of flow characteristics on the efficiency of the cooling tower. Experiments were conducted to study how adjustment of one or both parameters affect the amount of heat removed from the hot water by the water heater. A daily record of dry and wet bulb temperatures in Uyo metropolis for one complete year was obtained and the maximum wet and dry bulb temperatures of 27°C and 31°C respectively which represented the worst-case scenario was used for the design of the cooling tower. The tower had a resulting designed efficiency of 51.6%.

The results were used to plot a graph of cooling rate of the hot water, from a temperature of 82°C to 40°C in one hour by the cooling tower with an approach of 14°C. The variation of water temperature with the flow rate was a non-linear one, from 43°C to 67.5°C and from 67.5°C to 82°C respectively. It was inferred from this investigation that the rate of cooling of water is uniformly proportional to the flow rate to an extent. Thus, variation of the cooling tower characteristics affects the tower performance linearly and non-linearly. The actual efficiency of the cooling tower was calculated and found to be 47.5% which is 4.1% lower than the designed efficiency.

The objectives of this research are to determine the cooling capacity (the heat load) of the cooling tower, to evaluate the tower efficiency and effectiveness of the cooling tower and to analyze the cooling tower evaporation, drift, blow down or wind age losses and proffer measures for reducing the losses and improving the cooling tower efficiency.

This research work will help in minimizing the frequent problems of heat transfer and the heating processes affecting the urea fertilizer production. An accurate prediction of the performance of a cooling tower, with the corresponding detailed evaluation of its thermodynamics variables, will help to avoid undesirable or abnormal operating conditions or to anticipate solutions to certain unusual operating conditions like those derived from maintenance labour. It is also significant as it may serve as an aid and guide to future research on assessing the thermodynamic performance of cooling tower having different specification and operating in other production industries.

## MATERIALS AND METHODS

### 2.1 Materials

The materials utilized in this research which aided

$$CR = T_{cw\epsilon} - T_{cwout} \quad (1)$$

Where  $T_{cwin}$  is inlet cooling water temperature,  $T_{cwout}$  is outlet cooling water temperature.

### 2.2.2 Cooling Tower Approach (CA)

The difference between the cold-water temperature and the outlet wet-bulb temperature is given as (Nag, 2013):

$$CA = T_{cwout} - T_{wbout} \quad (2)$$

Where  $T_{wbout}$  is outlet wet-bulb temperature?

Wet-bulb temperature is measured using a thermometer with the bulb wrapped in wet muslin or cloth.

### 2.2.3 Cooling Tower Effectiveness ( $E_{ct}$ )

It is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature. It is given as (Nag, 2013):

$$E_{ct} = \frac{Range}{Range+Approach} \times 100 \quad (3)$$

Substituting equations (1) and (2) into equation (3), we have:

the analysis in MATLAB are relative humidity of the ambient air, wet-bulb temperature, water circulation rate, air velocity through the tower's air passageways, the tower height, enthalpies of air-water vapour mixtures at inlet and exhaust section of the cooling tower streams collected from the Cooling tower manufacturer's manual and operational logbook of the Indorama Eleme Petrochemical Company Limited while the values of the enthalpies of air-water vapour mixtures at inlet and exhaust section are gotten using psychrometric charts or saturated water-temperatures tables. The cooling tower performance parameters to be analysed are Range, Effectiveness, Cooling capacity, Evaporation losses, Cycles of concentration, and Cooling tower Efficiency of the tower.

## 2.2 Methods

The following step by step approaches are employed in arriving at the desired objectives:

### 2.2.1 Cooling Tower Range (CR)

This is the difference between the cooling tower hot water temperature at the inlet and the outlet water temperature, which is given as (Nag, 2013):

$$E_{ct} = \frac{ct - T_{cw} - T_{cwout}}{(T_{cw} - T_{cwout}) + (T_{cwout} - T_{wbout})} \times 100 \quad (4)$$

Equation (4) can be rewritten as:

$$E_{ct} = \frac{T_{cw} - T_{cwout}}{T_{cw} - T_{wbout}} \quad (5)$$

Where:

$T_{wbout}$  = Outlet web-bulb temperature

### 2.2.4 Evaporation Losses (EL)

As the water in the cooling tower circulates in the system, some evaporates during the process resulting to loss of water quantity in the system. Thus, evaporation loss is calculated using (Nag, 2013).

$$E_L = \frac{Q_w \times (T_{cw} - T_{cwout}) \times C_p}{H_v} \quad (6)$$

But, from equation (1):

$$CR = T_{cw} - T_{cwout}$$

Substituting equation (1) into equation (6) the evaporation loss becomes:

$$E_L = \frac{Q_w \times CR \times C_p}{H_v} \quad (7)$$

### 2.2.5 Blow down (BL)

It is when water is used to discharge or remove high mineral contents, impurities and sediment that can corrode the system. Blow down is calculated as (Nag, 2013):

$$B_L = \frac{\text{Evaporation Loss}}{\text{Cycle of Concentration} - 1} \quad (8)$$

Substituting equation (7) into equation (8), we have:

$$B_L = \frac{Q_w \times CR \times C_p}{H_v} \div (COC - 1) \quad (9)$$

Where:

CR = Cooling tower range

$H_v$  = Latent heat of evaporation of water

$Q_w$  = Water circulation rate

COC = Cycle of Concentration

Equation (9) can be rewritten as:

$$B_L = \frac{Q_w \times CR \times C_p}{H_v (COC - 1)} \times 100 \quad (10)$$

The percentage of blow down loss is given as:

$$\% B_L = \frac{B_L}{Q_w} \times 100 \quad (11)$$

**2.2.6 Mass of Water (Mw)**

The mass of water in cooling tower is given as (Nag, 2013):

Mw= hold up volume

(Circulating water volume) x water

Density (12)

**2.2.7 Drift Loss (DL)**

The drift loss of cooling tower is given as (Nag, 2013):

$$D_L = \frac{0.20 \times Q_w}{100} \quad (13)$$

**2.2.8 Windage Loss (WL)**

The windage loss of cooling tower is given as (Nag, 2013):

$$W_L = \frac{0.005 \times Q_w}{100} \quad (14)$$

**2.2.9 Make -up Water Consumption (M<sub>c</sub>)**

Water make- up of a cooling tower is necessary to replace the mechanical carryout of water droplets (windage), evaporation and the blow-down required to maintain a controlled solids buildup. Make up water is usually added to the cooling tower basin. It can be calculated as (Nag, 2013):

$$M_c = E_L + D_L + B_L + O_L \quad (15)$$

**2.2.10 Pumping Power(P<sub>p</sub>)**

Pp= Circulating water volume x density of water x pumping distance. (16)

**RESULTS AND DISCUSSION**

For an effective evaluation of the efficiency and effectiveness of the performance of Indorama Eleme.

Petrochemical Limited cooling tower operations, certain relevant data are obtained such as Table 1 below critical to evaluating the thermodynamic performance of the cooling tower in MATLAB computer program.

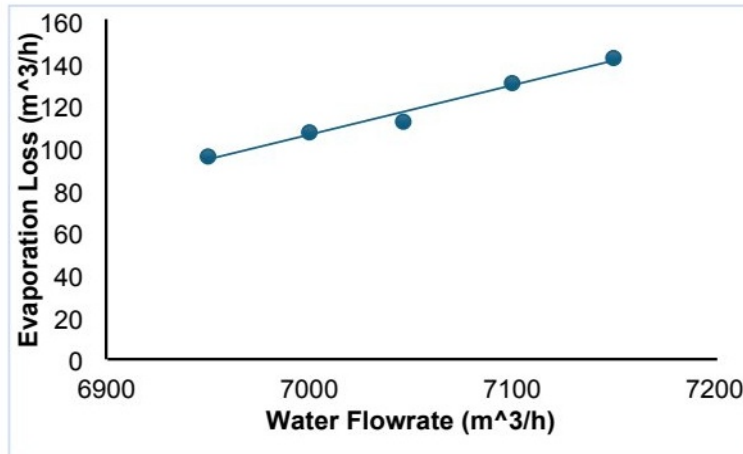
**Table 1: Simulation Result of Cooling Tower**

Tcwi n(°C)	Tcw_ou t (°C)	Twb i n(°C)	Twb_ou t(°C)	CSW	MSC	CR	CA	Qw (m3/h)	Q (MW)
						(°C)	(°C)		
36	27	28	23	212	110	9	4	6950	72.73
40	30	30	25	418	114	10	5	7000	81.39
				800	130	10.4		7046.	
44	33.6	32.6	27.3				6.3	3	85.21
48	36	34	29	803	105	12	7	7100	99.07
				990	100	13			108.0

52	39	36	31			8	7150	8
----	----	----	----	--	--	---	------	---

### 3.1 Determination of Evaporation Loss of the Cooling Tower

Figure 2 shows the variation of evaporation loss with water volume flow-rate.



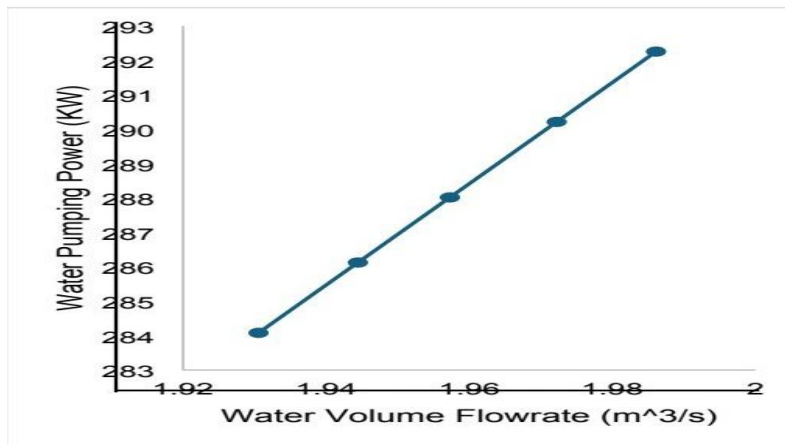
**Figure 2: Variation of Evaporation Loss with Water Volume Flow rate**

The results obtained indicate that as the water volume flow rate increases, evaporation loss also tends to rise. This aligns with the principle that higher water flow rates lead to increased contact between water and air, promoting evaporation. For example, at a water volume flow rate of 6950 m<sup>3</sup>/h, the evaporation loss is 95.70 m<sup>3</sup>/h, and it increases

to 142.21 m<sup>3</sup>/h at a flow rate of 7150 m<sup>3</sup>/h.

### 3.2 Determination of Water Pumping Power of the Cooling Tower

Figure 3 was drawn from the table in Appendix IB and it shows the variation of water pumping power with water volume flow-rate.



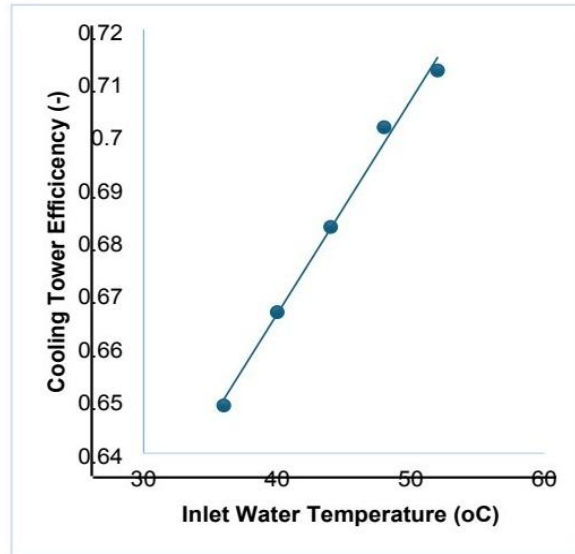
**Figure 3: Variation of Water Pumping Power with Water Volume Flow-rate.**

Results obtained show that as the water volume flow-rate ( $Q_w$ ) increases from 1.93 m<sup>3</sup>/s to 1.99 m<sup>3</sup>/s, the pumping power also increases from 284.08 kW to 292.26 kW. This indicates a positive correlation between water volume flow-rate and pumping power. Figure 3 illustrates that as the flow rate of water increases the pumping power increases,

because higher water flow rate enables heat and mass transfer between the air and water.

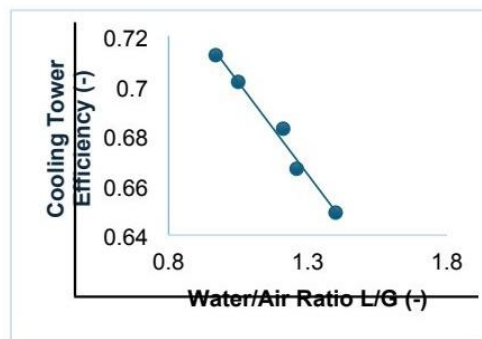
### 3.3 Determination of Cooling Efficiency of the Cooling Tower

Figure 4 shows the variation of cooling efficiency with inlet water temperature.



**Figure 4: Variation of Cooling Efficiency with Inlet Water Temperature.**

Results obtained shows that as the inlet water temperature increases from 36°C to 52°C, the tower efficiency increases from 65% to 71%. The higher the tower efficiency, the better the cooling performance.



**Figure 5: Variation of Cooling Efficiency with Liquid-Gas Ratio.**

Figure 5 shows the variation of cooling efficiency with liquid-gas ratio. Results obtained show that as

the water-gas ratio decreases from 1.4 to 0.97, the cooling tower efficiency increases from 65% to 71%.

The tower efficiency is influenced by the liquid-gas ratio, with higher efficiency is observed at lower ratio. This relationship is important for optimizing the balance between liquid and gas in the cooling process.”

### 3.4 Validation of Research Results

Result obtained in this study for cooling

range at an inlet water temperature of 36°C is 9°C. This is in line with Fadhil et.al. (2021) as shown in Figure 6. Also, the tower efficiency at this same temperature (36°C) is 65%, which is also in line with Fadhil et al. (2021), where the thermal efficiency obtained with respect to the inlet water temperature is 65% as shown in Figure 7

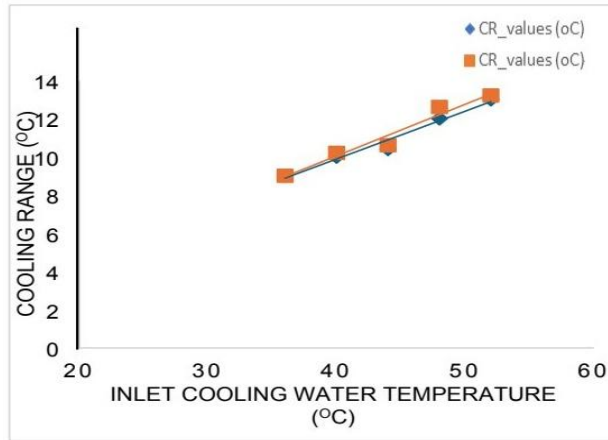


Figure 6: Validation of Cooling Range with Inlet Water Temperature (Fadhil et al., 2021)

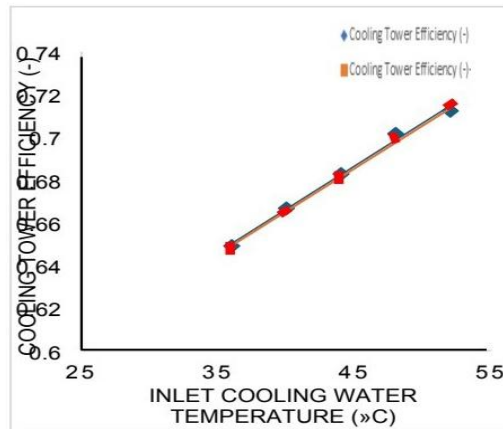


Figure 7: Validation of Cooling Efficiency with Inlet Water Temperature (Fadhil et al., 2021)

### CONCLUSION

The aim of this research is to analyze the cooling tower characteristics of Indorama Eleme Petrochemical Company Limited. It involves the evaluation of the specific humidity of inlet and outlet air, the range, approach, effectiveness, cooling

capacity, evaporation losses, cycles of concentration, liquid to gas ratio, and cooling tower thermal efficiency of the tower respectively using the operational data critical to evaluating the performance of the cooling tower.

The tower efficiency and effectiveness were

successfully evaluated. Figures 4 and 5 demonstrated how cooling efficiency increases with higher inlet water temperatures and lower liquid-gas ratios. These findings contribute to a nuanced understanding of the cooling tower's performance and provide insights into optimizing its efficiency. The study thoroughly analysed different types of losses, including evaporation loss, drift loss, blow-down rate, windage loss, and pumping power. The results in Figure 2 not only quantified these losses but also suggested measures for improvement. For instance, the inverse relationship between cycle of concentration and blow-down rate indicates a potential strategy for water conservation. This research has contributed to knowledge by providing a method of evaluating the performance of the cooling tower by modeling the thermodynamic equations in the MATLAB Simulink as provided by this research.

## **REFERENCES**

- Chan, M. H. (2015). Cooling Tower Performance Analysis and Visible Air Plume Abatement in Buildings Situated in Temperate Climate Zone. PhD Degree Thesis, Welsh School of Architecture, Cardiff University.
- Dastia, Z. A., Iftikhar, A. & Khalid, Q. (2020). Assessment Lagging Performance Indicators of Cooling Tower Water Wastage at Refinery (Parco) & Possible Up gradations to Eco Design for Water Conservation. *American Scientific Research Journal for Engineering, Technology, and Sciences*, 66(1), 68-94.
- Dhruvit, J. & Chetan, J. (2016). Cooling Tower Performance and Determining Energy Saving Opportunities through Economizer Operation: A Review. *IOSR Journal of Mechanical and Civil Engineering*, 13(1), 1-12.
- Fadhil, A. K., Doaa, Z. K., Mustafa, J.A. & Yasser, A. L. (2021). Effect of the Water Inlet Temperature and Flow Rate on the Energy and Exergy Performance of a Forced Draft Counter Wet Cooling Tower, *Research Square*, 1-12.
- Indorama Eleme Petrochemical Limited (2022). Indorama Eleme Petrochemical Company Limited: Establishment and Products, 21th May, 2022.
- Kiran, B. N., Choudharya, V., Muthukumara, P. & Somayajia, C. (2017). Performance Assessment of a Counter Flow Cooling Tower Unique Approach. *International Conference on Recent Advancement in Air Conditioning and Refrigeration*, Bhubaneswar, India, 10-12.
- Kloppers, J. C. & Kroger, D. G (2003). Loss Coefficient Correlation for Wet Cooling Tower Fills. *International Journal of Applied Thermal Engineering*, 23(17), 2201-2211.
- Mustafa, J., Al-Dulaimi, F., Abdulrazzaq, K. & Faik, A. H. (2020). Evaluation of Thermal Performance for Natural and Forced Draft Wet Cooling Tower. *Journal of Thermal Engineering*, 7(10), 112-123.
- Nag, P. K. (2013). *Power Plant Engineering*, 3rd edition, Malayan Colleges, Laguna.
- Ovat, F. A. & Anyandi, J. A. (2002) Design and Performance Evaluation of A Cooling Tower Based On Different Parameters. *Journal of Science, Engineering and Technology*. 6(2), 38-47
- Piyush, Y., Sagar, G., Bhushan, P., Krushna, K. & Dube, A. S. (2016) Performance Evaluation of Evaporated Water in Cooling Towers. *Energy conversion and management*, 13(8), 1455-1460.
- Pushpa, B. S., Vasant, V. & Nimbalkar, P. T. (2014). Performance Evaluation of Cooling Tower in Thermal Power Plant. A Case Study of RTPS, Karnataka, *International Journal of Engineering and Advance Technology*, 4(2), 1-14.
- Rohan, K. & Naveen, S. (2019). Design and Performance Analysis of Cross Flow & Force Draft Cooling Towers. *International Journal of Engineering Research & Technology*, 8(7), 398-403.
- Satish, K. M.V.H. (2016) Performance Analysis of Cooling Tower. *International Journal of Engineering Trends and Technology*, 9(4), 442-448.

Shivam, M. & Arvind, G. (2018). Thermal Performance Analysis and Design Modification of Natural Draft Wet Cooling Tower. International Journal of Creative Research Thoughts, 6(1), 178-186.

Vishnu, S. K. & Reji, M. (2018). Performance Analysis and Optimization of Cooling Tower.

International Journal of Scientific and Research Publications, 8(4), 225-237.

Yagnesh, S. A., Sarfaraz, M.K., Shyam, P. L., Darshnesh, B. P., Dhruv, V. P. & Jhanbux, M. V. (2017). Performance Analysis of Cooling Tower in Process Industry, Mechanical Engineering, India, 3(6), 1722-1730.