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Optimizing Cooling Tower Performance: Loss Analysis and Efficiency Enhancement Strategies

Ajith Krishnan K
Lecturer, Department of Marine technology, National College, Kerala

***Abstract:** Cooling tower are essential components in industrial heat rejection systems, where performance losses directly affected operational efficiency and energy consumption. This study presents a performance analysis of a mechanical draft cooling tower, focusing on identification and evaluation of major losses. Parameters such as water inlet and outlet temperature, wet-bulb temperature, and flow rates were measured under load condition. Losses due to evaporation, Drift, blow down, and heat exchange inefficiencies were quantified. Results show that these losses contribute to overall efficiency reduction. Based on the findings, improvement strategies such as effective use of drift eliminator, precise fan speed control, and setting blade angle are proposed. Implementation of these measures can enhance efficiency; reduce water wastage and low operating cost. The study provides a practical framework for diagnosing cooling tower losses and guiding efficiency enhancement in industrial applications.*

***Keyword:** Cooling tower, Performance analysis, Efficiency improvement, Heat transfer, Approach temperature, Range temperature, Thermal performance.*

I. INTRODUCTION

Cooling towers are essential heat rejection device used extensively in power plants, refineries, HVAC systems, and various industrial processes. Their primary function is to remove low-grade heat from circulating water by transferring it to atmosphere, ensuring efficient operation of downstream equipment. By enabling the reuse of cooled water, cooling tower significantly reduce the demand for fresh water, thus lowering operational cost and environmental impact.

Cooling tower depends on multiple interrelated parameters including heat transfer efficiency, air flow pattern, fill characteristics, drift losses, and blow down losses and also considered fan performance. Losses in cooling tower can categorize into:

Thermal losses : Reduce the heat rejection due to inadequate contact between air and water or improper fill design.
Water losses : Drift loss, Evaporation loss and Blow down loss.
Energy losses : Excessive fan and pump consumption due to aerodynamic inefficiencies or mechanical issues.

Optimizing performance of cooling tower has become a key focus in industrial operations. Enhancement strategies may include the use of high efficiency fill materials, drift eliminators, optimizing fan control, uniform water distribution and regular maintenance to prevent scaling.

This project focus on analyzing performance losses in cooling towers and developing targeted enhancement strategies to maximize performance, minimize water and energy losses and extend service life. The study involves: Performance benchmarking under existing operational conditions of the cooling tower, detailed loss analysis through measurement and analysis, implementation of operational modifications and Evaluation of improvements in efficiency and cost savings.

By integrating experimental measurements with analytical evaluation, the project aims to deliver a practical framework for sustainable and high efficiency cooling tower operation suitable for diverse industrial applications.

II. PERFORMANCE ASSESSMENT OF COOLING TOWER

In operational performance assessment, the typical measurements and observations involved they are cooling tower design data and curves to be referred to as the basis, intake air WBT and DBT at the each cell, Exhaust air WBT and DBT at each cell, cooling water inlet and outlet temperature, process data on heat exchangers and relevant data for calculations. Instruments used for this purpose are whirling psychrometer which is used to measure dry bulb temperature and wet bulb temperature of atmospheric air. Anemometer is used here for measuring the velocity of hot air leaving the cooling tower cell and ultrasonic flow meter is used to measure the flow of water to the cooling tower cell.

Here, considering cooling tower in RGCCPP, Kayamkulam which has 8 cells and it has one cooling tower fan.

Table 1: Specifications of cooling tower

SPECIFICATIONS	
Tower type	Induced draft counter flow
Cooling water flow	23,000
Type of fill	Film (PVC)
Range of cooling	11°C
Approach	5°C
Year of commissioning	1999
L/G Ratio	1.437
No. of cells	8
Cooling water flow kg/hr. per m² of fill area	12128.75
Dry air flow kg/hr. per m² of fill area	8440.32
Type of construction	R.C.C
Total tower wetted surface	4291107m²

A. Effectiveness of Cooling Tower

Range	= Inlet cooling water temperature - Outlet cooling tower temperature
Inlet cooling water temperature	= 43.44 °C
Outlet cooling water temperature	= 34.55 °C
Range	= 43.44 - 34.55
	= 8.89 °C
Approach	= Outlet cooling tower temperature - Wet bulb temperature
Outlet cooling tower temperature	= 34.55 °C
Wet bulb temperature	= 26.55 °C
Approach	= 34.55 – 26.55
	= 8 °C
Effectiveness	= Range/ (Range + Approach) x 100
	= 8.89/ (8.89 + 8)
	= 52.63 %

B. Heat Load Calculations

L/G ratio	= 1.437
Air velocity at face	= 2.70 m/sec
Air volumetric flow	= 2.76 m³/sec
Face area	= Air volumetric flow / Air velocity at face
	=1.022 m²
Air density	= 1.18 kg/m³
Specific heat of water	= 4.186 kJ/kg-k
Mass flow rate of air	= Air density x Air volumetric flow
	= 1.18 x 2.76
	= 3.25 kg/sec
Mass flow rate of water	= L/G ratio x Mass flow rate of air
	= 1.437 x 3.25
	= 4.67 kg/sec
Water volumetric flow	= Mass flow rate of water/ Density of water
	= (4.67/1000) x 3600
	= 16.81m³/hour

Heat load = Mass flow of water x Specific heat of water x Range
= 4.67 x 4.18 x 8.89
= 173.53 kW = 592103 BTU/hour

The performance evaluation of the cooling tower under the given operating conditions range of 8.89°C, approach of 8°C, effectiveness of 52.63%. The calculated heat load is 173.53kW.

III. DIFFERENT LOSSES AFFECTING THE PERFORMANCE OF COOLING TOWER

A. Evaporation Loss

Evaporation Loss = 0.001 x Water volumetric flow x Range
= 0.001 x 16.81 x 8.89
= 0.1494 m^3/hour
= 0.1494 x 1000 =149.4 L/hour
= 149.4 x 24 = 3585.6 L/day

B. Drift Loss

Drift before eliminator (0.05% = 0.0005)
Drift loss = Drift fraction x Circulating water flow rate
Volume = 0.0005 x 16.81
= 0.008405 m^3/hour
= 0.008405 x 1000 = 8.405 L/hour
= 8.405 x 24 = 201.72 L/day

Drift after eliminator (0.02% = 0.00002)
Volume = 0.00002 x 16.81
= 0.0003362m^3/hour
= 0.0003362 x 1000 = 0.3362 L/hour
= 0.3362 x 24
= 8.06 L/day

C. Blow down Loss

Blow down losses = Evaporation losses / (C.O.C-1)
Cycle of concentration = 4
= (0.1494 x 24) / (4-1)
= 3.58/3
=1.1952mA³/day
= 1.1952 x 1000
= 1195.2 L/day

Total make up water required per day = Evaporation losses + Drift losses after use of eliminator + Blow down losses
= 3585.6 + 8.06 + 1195.2
= 4788.86 L/day

D. Electric Power Consumption of Fan

Aerodynamic power = Pressure x Air volumetric flow
= 150 x 2.76
= 414 W

For light shaft,
Efficiency of fan is 65% and Efficiency of motor is 92%
Power required for shaft = 2.76 x 150/0.65
= 637.54 W
Electric input power = 0.63754/0.92
= 0.692 KW

For Heavy weighted shaft,

Power required for shaft	= 0.63754 x 1.06
	= 0.675 KW
Electric input power	= 0.675/0.92
	= 0.734 KW

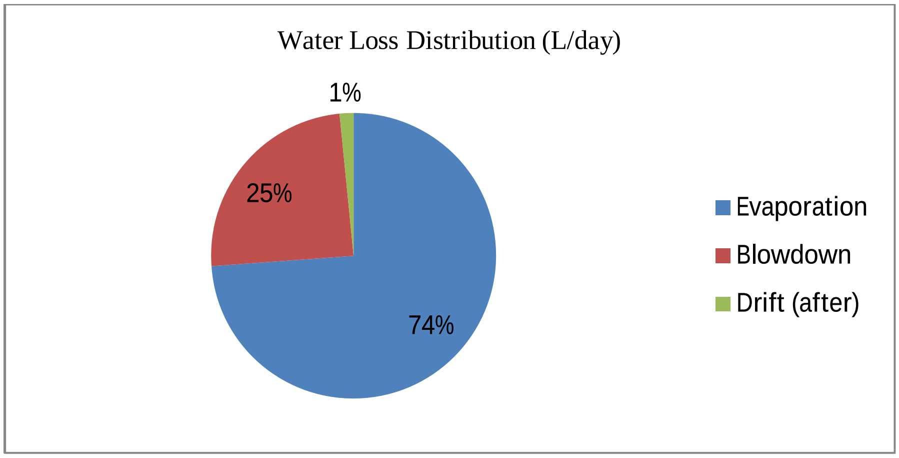

Fig 1: Water Loss Distribution (L/day) – After Eliminator

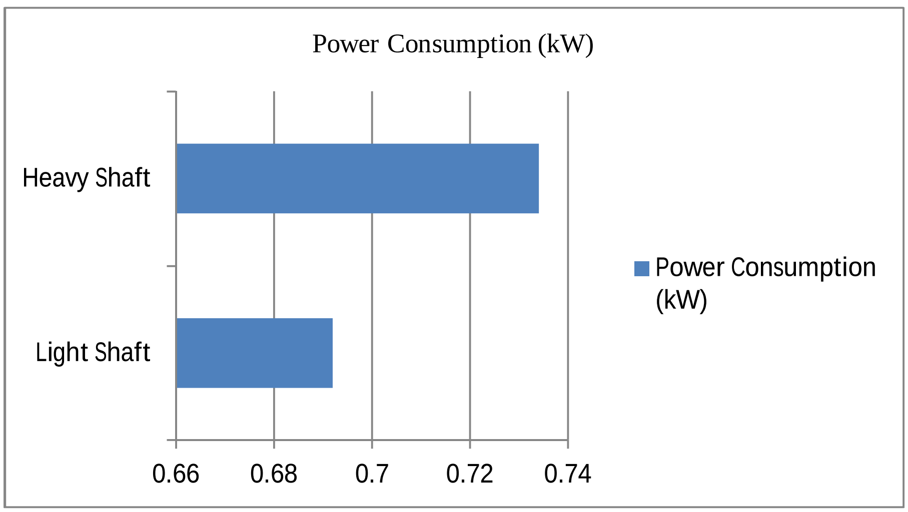

Fig 2: Power Consumption: Light Shaft v/s Heavy Shaft

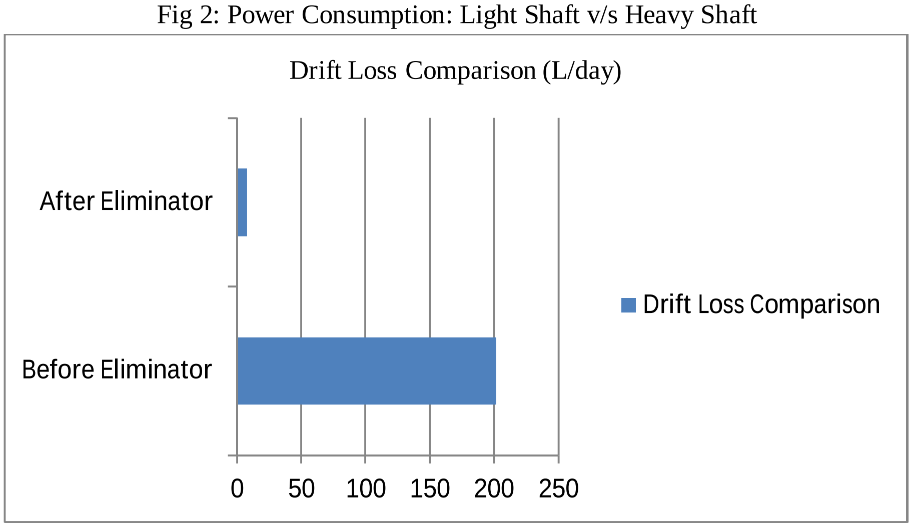

Fig 3: Drift Loss: Before and after Eliminator

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Water loss analysis revealed an evaporation loss of 3585.6L/day, drift loss after drift eliminator 8.06L/day and blowdown loss of 1195.2 L/day, as the result of this total make up water is 4788.86L/day. Energy analysis showed that the use of increase electric power consumption from 0.692kW to 0.734kW representing a 5.71% increase in daily energy use. This highlights that both water conservation through drift eliminators and energy optimization through light weight fan shaft design can significantly improve the performance of cooling tower.

Optimized blow down control and improved drift elimination reduce total water loss, enhance cooling efficiency and sustainability.

IV. STRATEGIES FOR IMPROVING COOLING TOWER PERFORMANCE

The investigation revealed that the evaporation loss accounted for approximately 74% of total water loss while blow down loss contribute significantly around 24% due to elevated cycle of concentration, and drift loss was minimized by drift eliminators but still measurable. Based on the findings, the following strategies are recommended:

A. Mechanical & Operational Enhancement

Fan drive optimization, given the high shaft power requirement observed, implementing variable frequency drive to match air flow with load demand, reduce excess power consumption during low cooling load periods. Nozzle performance improvement, replace partially clogged or worn spray nozzles to ensure uniform water distribution, enhance heat transfer and reducing approach temperature. Fill pack maintenance, clean or replace fouled fill media to increase contact surface area and improve thermal efficiency without increasing fan energy. Drift eliminator upgrade, although drift loss is low, replacing aged eliminator blades can further minimize drift related loss.

B. Water Treatment & Loss Reduction

Optimize cycles concentration, reduce blow down by implementing conductivity based blow down control, targeting the maximum safe C.O.C without risking scaling. This could save up to 20 to 25% of blow down volume based on measured conductivity. Scale and corrosion control, continue chemical dosing with scale inhibitors and corrosion protectants adjusted to actual water chemistry, preventing tube scaling that can increase temperature approach. Makeup water quality improvement introduce to makeup water hardness is contributing factor to higher C.O.C and reduce blow down.

C. Monitoring & Control Measures

Installing continuous temperature, conductivity and flow monitoring to track range, approach, C.O.C and water balance in real time. Use the collected data for trend analysis to identify performance drop and optimize fan and blow down schedules seasonally.

D. Expected Outcomes

Water Saving: Reduction in blow down volume by up to 20 to 25%, directly lowering makeup water demand.

Energy Saving: Fan power reduction during partial load operation through VFD control could save 5 to 10% in energy cost annually.

Performance Stability: Maintaining clean fill and optimized C.O.C will help sustain approach temperature with in design limit, preventing capacity loss during peak load.

V. CONCLUSION

The study on cooling tower performance revealed that evaporation loss is the primary contributor to total water loss, followed by blow down and drift. Optimization through controlled blow down, effective water treatment and improved drift eliminators can significantly enhance efficiency and reduce makeup water demand. These strategies ensure better thermal performance, lower operational costs and promote sustainable operation. The study confirms that targeted optimization leads to reliable and eco-friendly cooling tower performance.

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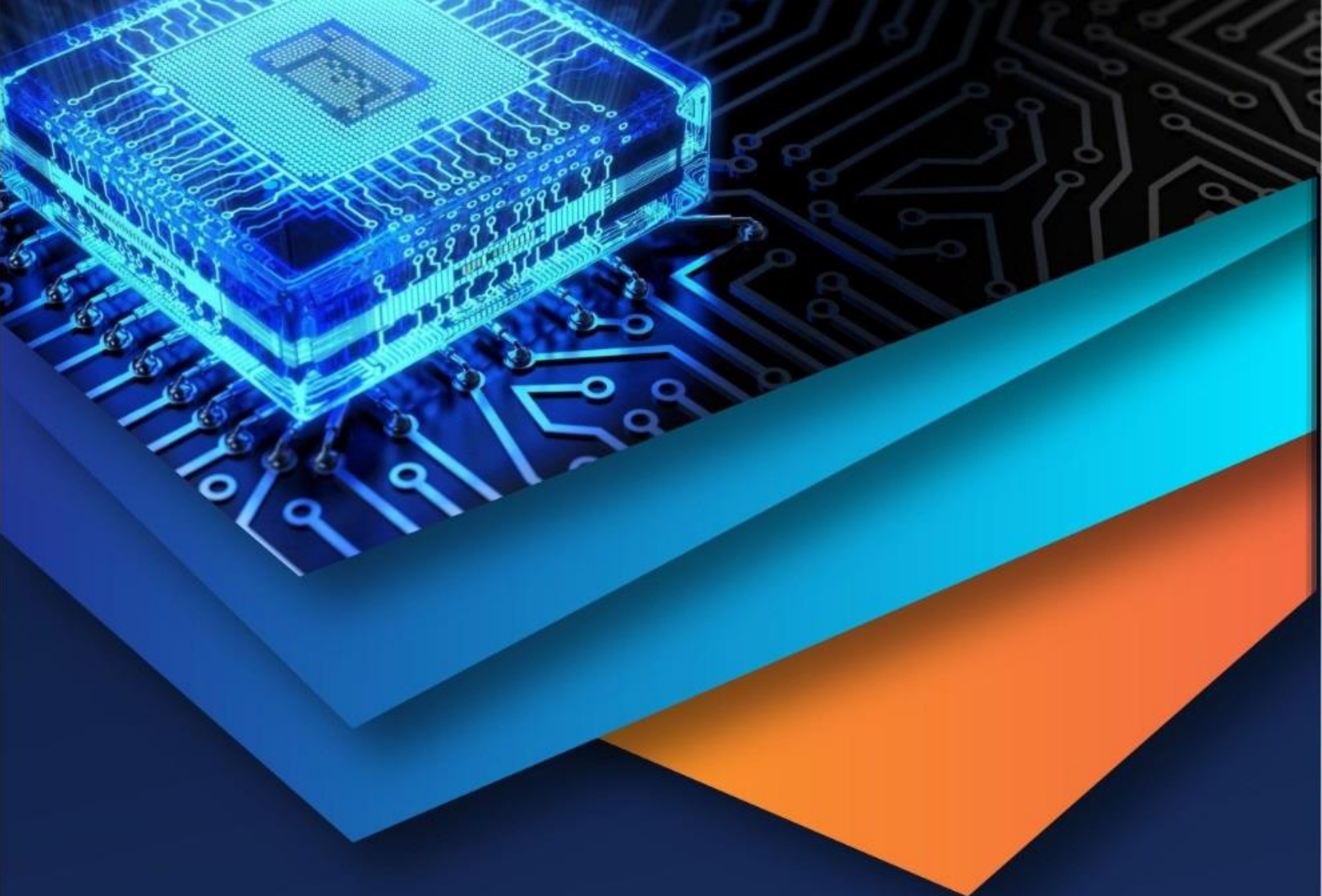

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