CONTROL OF LOSSES IN EVAPORATIVE CONDENSERS & COOLING TOWERS

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Abstract - *This research explores the significance of energy conservation in the context of rising energy consumption and its impact on economic growth. With a focus on cooling systems, particularly evaporative condenser technology, the study aims to investigate its fundamentals, operating principles, and theoretical aspects. Evaporative condensers and cooling towers are critical components in industrial cooling systems, playing a vital role in dissipating heat from processes and maintaining operational efficiency. However, losses in these systems, both in terms of water and energy, can significantly impact performance, environmental sustainability, and operational costs. This research addresses methods and strategies for controlling losses in evaporative condensers and cooling towers, focusing on water consumption, energy efficiency, and system performance optimization. Key factors such as chemical consumption, evaporation, leakage and heat exchange inefficiencies are analyzed. The paper discusses technological advancements, maintenance practices, and control systems that can minimize these losses, including the use of advanced water treatment processes, airflow management, and energy recovery solutions. By adopting these control measures, industries can achieve reduced operational costs, minimized environmental impact, contributing to the overall sustainability of industrial cooling processes.*

***Key Words*: Evaporative condensers, cooling towers, energy conservation, water losses, heat transfer efficiency, industrial cooling systems, evaporation losses, energy efficiency optimization, water treatment, airflow management, system performance improvement, sustainability.**

1. INTRODUCTION

Evaporative condensers and cooling towers are integral to a wide range of industrial systems, especially in large-scale refrigeration, air conditioning, and power generation. Across the globe, these systems operate on the fundamental principle of evaporative cooling to reject heat from industrial processes. With the global rise in industrial demands, there is increasing awareness regarding the efficiency of these systems, with significant efforts focused on reducing operational losses such as heat, water, and energy losses. The efficiency of evaporative cooling technologies is essential not only to enhance productivity but also to minimize the environmental impact by reducing water consumption, energy use, and chemical discharge. Globally, advancements in water treatment, cooling technologies, and integrated systems are helping to optimize the use of resources, such as the use of biocides for microbial control, corrosion inhibitors, and specialized coatings to prevent scaling on condenser coils. Many industrialized countries are now prioritizing sustainability, leading to the adoption of advanced filtration, effluent treatment systems, and chemical dosing technologies, which improve cooling system performance while ensuring compliance with environmental standards.

In India, industries ranging from food processing, chemical manufacturing, and HVAC systems rely heavily on evaporative condensers and cooling towers to remove heat from various processes. However, India faces unique challenges when it comes to cooling system efficiency. These include water scarcity, frequent power outages, and the growing costs of industrial water usage. In response, Indian industries are increasingly focusing on optimizing the quality of water used in cooling systems to reduce costs and minimize water waste. As part of this trend, the use of treated effluent (ETP water) for cooling systems is becoming more widespread. The primary advantage of using ETP water is the reduction in fresh water consumption, thus reducing costs and addressing environmental concerns. Cooling tower and evaporative condenser maintenance also involves optimizing water quality to prevent scaling, fouling, and microbial growth, which otherwise reduce heat exchange efficiency. Furthermore, the installation of Plate Heat Exchanger (PHE) systems has been promoted to better control temperature parameters and reduce evaporation losses, which are crucial for the country's growing industries where water and energy conservation are priorities.

The project focuses on optimizing the efficiency of the five evaporative condensers and four cooling towers used in the company's cooling systems.

2. LITERATURE REVIEW

B. Kiran Naik, P. Muthukumar. [December-2013][1] observed that the peak hour (2 pm) water loss was about 3.4 lit/hr-TR corresponding to 34 °C DBT and 31.5 °C WBT recorded on 22/08/2013.

K. A. Manske, D. T. Reindl, S. A. Klein. [July 2001] [2] Studied head pressure control, condenser sizing, and fan control are strongly interconnected and affect total energy consumption. Proper control reduces compressor workload and improves overall system efficiency. Simulation results showed about 11% reduction in annual energy consumption after applying optimized control strategies. Oversized condensers allow lower operating pressure and better energy savings during most operating conditions. Variable fan speed control is the most energy-efficient method for part-load operation. The study provides a practical method to determine optimal control settings for real industrial systems.

Janusz Pospolita , Anna Kuczuk, Katarzyna Widera, Zbigniew Buryn, Robert Cholewa, Andrzej Drajczyk, Mirosław Pietrucha, Rafał Smejda. [2022] [3] studied by that evaporation is the dominant source of water loss in cooling towers, accounting for about 80.9%, while drift losses, though smaller, remain significant. The study emphasizes that environmental conditions such as higher temperatures and increased wind speed can substantially raise water losses, with wind alone increasing losses by up to 23%. It also explains that reducing water flow leads to higher condenser temperature and pressure, which in turn decreases turbine efficiency. Overall, the research concludes that proper control of water flow and optimization of cooling tower operation are essential for improving plant performance, while efficient management can significantly reduce water consumption and operational costs.
Mr. N. Thiru Senthil Adhiban, M. Sukel Ahamed, S. Sugumar, P. Nethaji [June2022][4] used an evaporative condenser, as opposed to an air-cooled condenser, leads to a significant reduction of 58 % in power consumption and a notable improvement of 113.4 % in coefficient of performance (COP).
Habibur Rahman, Altab Hossain, Mohammad Ali. [Oct2024] [5] Nanofluids significantly improve heat transfer performance. Higher thermal conductivity enhances cooling efficiency. NTU is highest at the lowest flow rate (0.033 kg/s). Increasing nanoparticle concentration improves performance. Al_2O_3, ZnO, and Ti_2O_3 all show better results than water. Cooling efficiency increases with temperature. Nanofluids can reduce energy consumption. Proper stabilization is necessary for effective performance. Nanofluids can reduce water usage in cooling towers. Overall, nanofluids are a promising solution for advanced cooling systems.
J. Dixon Jim Joseph, K. Rajan Chakravarthi, M. Sarathkumar, V. Sharan Raghul, M. Vijay Kumar [2017] [6-8] studied. Condenser performance directly affects power plant efficiency. Lower condenser pressure improves turbine output. Efficient cooling increases overall plant efficiency. Proper water flow control is essential. Monitoring temperature and pressure is important. Fouling and corrosion must be minimized. Surface condensers are more efficient than other types. Improved cooling methods enhance performance. Optimization reduces energy loss and operating cost. Regular maintenance ensures long-term efficiency.

3. PROBLEM STATEMENT

Rusting found on the condenser, cooling tower body parts (sump, tubes, motor, shaft).Filles life span also reduced due to water quality. Soft water consumption is also high. Evaporation and blowdown losses increase.

4. METHODOLOGY

- Continuous monitoring of water quality, like PH, TDS, Hardness, water temperature, and Microbiological parameters.
- Planning to install a new DM plant to improve the quality of water. Also used ETP-treated water to DM plant feed to recycle and reduced the water purchasing cost from MIDC.
- Installation of PHE to drop down the temperature before sending to CT and evaporative condensers.
- All 5 condensers and 4 cooling towers, one by one, are cleaned with proper planning without disturbing plant operation.
- Check the difference in water parameters of feed water, sump/circulating water after use of DM water.
- Analysis of losses before and after the improvement of evaporation during full load and minimum load.

4.1 Materials Selection:

Installation of ETP RO & Cooling System for Utility Water Reuse:

1. Installation of ETP RO system to further treat Effluent Treatment Plant (ETP) outlet water for reuse.

2. Treated water is utilized in cooling towers and condensers, reducing fresh water consumption.

3. Plate Heat Exchanger (PHE) installed to reduce the temperature of ETP-treated water before reuse.

4. Development of a dedicated pipeline network for transferring RO-treated water to cooling towers and condensers.

5. Ensures efficient water recycling and improves overall plant sustainability.

6. Reduces operational costs by minimizing dependency on fresh/raw water sources.

7. Enhances environmental compliance through effective reuse of treated effluent.

4.2 Water parameters checking procedure:

1. Measure temperature of cooling towers by IR temperature gun.

2. Check water parameters PH by PH paper and indicators, COD by COD digester, BOD by BOD incubator machine, Hardness by hardness kit, free chlorine by chlorine kit.

3. Record water parameters before and after project completion.

Table 1: Water analysis of evaporative condensers and cooling towers

Water Parameter	Units	Before Project install
pH		9.8
Temperature	°C	40
Turbidity	NTU	36
Total Suspended Solids	Mg/l	38
Total Dissolved Solids	Mg/l	6800
Electrical Conductivity	µS/cm	10880
Total Hardness as CaCO3	Mg/l	140
Free Residual chlorine	Mg/l	3.2
BOD	Mg/l	180
COD	Mg/l	320

Table 2: ETP inlet water analysis

Parameters	Unit	Results
Ph	_	6.32
Total suspended solid	mg/l	64
Total dissolved solid	mg/l	2296
Chemical oxygen demand	mg/l	1768
Biological oxygen demand at 27°C for 3days	mg/l	472.09
Oil & Grease	mg/l	<5
Chloride	mg/l	434.9
Sulphate	mg/l	94.4

Table 3: ETP outlet water analysis

Parameters	Unit	Results
Ph	_	8.06
Total suspended solid	mg/l	8
Total dissolved solid	mg/l	1298
Chemical oxygen demand	mg/l	80
Biological oxygen demand at 27°C for 3days	mg/l	21.81
Oil & Grease	mg/l	<5
Chloride	mg/l	234.9
Sulphate	mg/l	<5

Condenser Data of Actual Plant:

Make: Evapco
Type: Evaporative Condenser
Capacity of each condenser: 580TR
Condensing Temperature:40˚C
Wet bulb Temperature:28˚C
Pump motor: 5.5 kW
Fan motor:22KW
Spray water flow: 76LPS
Actual temperatures from DCS:
Condenser sump 1=40 ˚C
Condenser sump 2=39 ˚C
Condenser sump 3=39.5 ˚C
Condenser sump 4=38.9˚C
Condenser sump 54=40.1˚C
Condenser liquid Header temperature =39.8 ˚C
Wet bulb temperature=25˚C
Average Humidity of year 2024 (RH)=48.75%
Water holding capacity of each condenser:
As per design water consumption each condenser
=Width of condenser sump x Length of condenser x Height of condenser sump
=5.632 x 3.607 x 0.750
= 15.2360m^3
Actual water consumption of each condenser
=Width of condenser sump x Length of condenser x Actual height maintain as per operation of condenser sump
= 5.632 x 3.607 x 0.500
= 10.1573 m^3

Total water consumption of 5 condensers
=10.1573 x 5 =50.7866 m^3
According to MIS (management information system) data per day consumption
=20 to 100 m^3 (It is based on load on compressors)

Table 4: Weather condition report

Months	Lowest Wet Bulb Temperature	Highest Wet Bulb Temperature	Humidity Percentage
JAN	16.8	28.3	37
FEB	19.6	28.3	29
APR	22.4	34.5	23
MAR	25.8	38	22
MAY	26.5	38.6	32
JUN	24.6	32.4	62
JUL	22.8	28.4	75
AUG	22.2	28	77
SEP	21.8	29	75
OCT	21.5	29.9	59
NOV	19	28.9	51
DEC	16.6	27.7	43

Range = $T_{out} - T_{in}$

If the water enters at 27 °C and exits at 40°C, then:

Range=40 – 29= 11 °C
Approach=$T_{out} - T_{wet\ bulb}$

Approach= 40 – 25 = 15 °C
Cooling Tower effectiveness in % = $\frac{Range}{(Range+Approach)}$ x 100%
= $\frac{11}{11+15}$ x100 = 0.423 x 100
=42.30%

Cooling capacity is the heat rejected in kcal/hr. or TR, Given as product of mass flow rate of water, specific heat and temperature difference.

Pump model no.: SCOT106

Motor Power : 7.5HP

Speed: 1450RPM

Impeller Diameter: 7.38inches

Phase/Voltage: 3/50/380-450

Seal: TCARSICAR (type of mechanical seal)

Cooling tower flow/Cell=225 m3/hr.

Cooling Duty Handled/Cell in kcal = Cooling tower flow/Cell x (Tout – Tin) x 1000

= 225 x (40 – 29) x 1000

=2475000 kcal/hr.

Evaporation Loss = 0.00085 x 1.8 x Circulation ratio(m3/hr.) x ($T_{out} - T_{in}$)

= 0.00085 x 1.8 x 225 x (40 – 29)

= 3.786 m3/hr. per Cell or Condenser

Percentage Losses = [Evaporation Loss / Cooling tower flow/Cell in m3/hr.] x 100

= [3.786 / 225] X 100

= 1.683%

Cycle of Concentration (COC) = TDS of Circulating water / TDS of Makeup water

= 6800 / 400

= 17

Blowdown requirement for site COC of 30.97 = Evaporation Loss / (COC – 1)

=3.786 / (17 -1)

= 0.236 m3/hr.

Makeup water requirement/cell in m3 /hr. = Evaporation Loss + Blowdown Loss

= 3.786 + 0.236

=4.022 m3/hr.

Heat Rejected = [Mc X Cp X (To – Ti)] / 3024

Mc = Mass flow rate of cooling water in Kg/hr.

Cp = Specific heat of water at kcal/kg °C.

Ti = Cooling water temperature at condenser inlet in °C.

To = Cooling water temperature at condenser outlet in °C.

Cp=1.0 kcal/kg at 27°C

Mc= 225000 kg/hr.

Ti= 27°C.

To= 33°C.

Heat Rejected = [225000 X 1.0 X (40-29)] / 3024

=2475000/ 3024

= 818.45 TR

Table 5: Pump & Fan current

Condenser no.	Equipment	Current
1	Pump	10.7
2	Pump	10.6
3	Pump	10.7
4	Pump	10.8
5	Pump	10.6
1	ID Fan	29.97
2	ID Fan	30.5
3	ID Fan	31.6
4	ID Fan	31.6
5	ID Fan	31

Table 6: Ambient Air analysis report

Parameters	Unit	NAAQ Standards	Result
Sulphur Dioxide (SO2)	µg/m3	≤80	22.47
Nitrogen Dioxide(NO2)	µg/m3	≤80	25.14
Particulate Matter PM10	µg/m3	≤100	46.5
Particulate Matter PM2.5	µg/m3	≤60	27.09
Ozone (O3) For 1Hrs	µg/m3	≤180	10.82
Ammonia (NH3)for 24Hrs	µg/m3	≤400	13.1
Carbon Monoxide (CO)	µg/m3	≤04	0.51
Benzene(C6H6)	µg/m3	≤05	<0.5
Benzo (a)Pyrene(BaP)	µg/m3	≤01	<0.02
Arsenic (AS)	µg/m3	≤06	<0.3
Nickel(Ni)	µg/m3	≤20	<0.3
Lead (Pb)	µg/m3	≤01	<0.003

5. RESULTS ANALYSIS:

Table 7: Comparison of improvement in water

Water Parameter	Units	Before	Present
pH		9.8	8.6
Temperature	°C	40	27
Turbidity	NTU	36	20.9
Total Suspended Solids	Mg/l	38	23
Total Dissolved Solids	Mg/l	6800	2120
Electrical Conductivity	µS/cm	10880	3250
Total Hardness as CaCO3	Mg/l	140	25
Free Residual chlorine	Mg/l	3.2	No FRC present
BOD	Mg/l	180	25
COD	Mg/l	320	52
Silica	Mg/l	40	4

5.1 Heat Load Calculation:

We used a plate-type heat exchanger to reduce inlet water temperature, which is coming from the ETP RO to feed into the cooling tower sump and evaporative condenser sump.

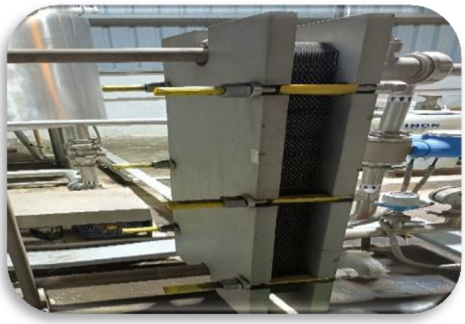

Fig.1 Plate Type Heat Exchanger

From fig no.1 plate type heat exchanger use to decrease temperature of cooling tower feed water. Make of plate type heat exchanger Kelvion India Pvt. Ltd. Having model, no :NT80M V-22PL. Design pressure of this exchanger is up to 10Bars. It can sustain temperature up to 100°C.

Fig.2 Temperature reading of water before using PHE

Fig.3 Temperature reading of water after using PHE

In above figure no.3 as we checked temperature of water reading by Fluke make infrared thermometer. After installing PHE we observed the temperature of sump up to 26.5 °C. Before installing PHE to feed water temperature was 31.5°C. which is hot for condenser compared to 26.5°C.

Fig.4 Temperature reading of water in the running condition of condenser

As shown in above figure no.4 we get a temperature reading 25.6°C in running condition of evaporative condenser and cooling tower.

Into this plate type heat exchanger, we given hot water at a temperature in range of 30 °C to 32°C which is we are using it directly to the condenser feed in the previous time before completion of project and other side cold temperature is used at 10°C to 13°C which comes from the whey RO generation from plant.

The heat load calculation after installing PHE is as follows:

T_{hi} = Temperature of hot fluid entering the heat exchanger in °C (31°C)

T_{ho} = Temperature of hot fluid out of the heat exchanger in °C (27°C)

T_{ci} = Temperature of cold fluid entering the heat exchanger in (10°C)

T_{co} = Temperature of cold fluid out of the heat exchanger in °C (14°C)

Log mean temperature difference

$$\Delta T_{LMTD} = \frac{[(Thi-Tco)-(Tho-Tci)]}{\ln\frac{(Thi-Tco)}{(Tho-Tci)}}$$

$$= \frac{[(31-10)-(27-10)]}{\ln\frac{(31-14)}{(27-10)}}$$

$$= 0/0$$

Temp. Difference is 17°C

Area of plate type heat exchanger is, [8]

Length = 1150mm =1.15m

Width =570mm = 0.570m

Thickness of plate =0.5mm = 0.005m

A = (N-1) X A plate

Where, N = Number of plates of plate type heat exchanger

A= Area of plate

A = (21 -1) x (0.570 x 1.15)

A = 13.11 m^2

So, the total area covered by the heat exchanger is 13.11 m2

Heat Transfer Rate: [9]

$Q = U \times A \times \Delta T_{LMTD}$

Where, U = Overall heat transfer coefficient in kcal/hr m2 °C

A= Heat transfer surface are in m2

Q = Rate of heat transfer between two fluids in kcal/hr

ΔT_{LMTD} = Log mean temperature difference in °C

Q = 3440.06 x 13.11 x 17

= 766686.17 kcal/hr.

= 891.058 kW.

Here, heat from the hot fluid at a rate of 891.058 kW is transferred to obtain water at a temperature of 27°C.

After fitted PHE parameters are changed as per below:

Condenser sump =27.24˚C

Condenser sump 2=25 ˚C

Condenser sump 3=26 ˚C

Condenser sump 4=26.8˚C

Condenser sump 5=27˚C

Condenser liquid Header temperature =36.5˚C

Wet bulb temperature=25˚C

Average Humidity of year 2024 (RH)=48.75%

Range is the difference between the cooling tower water inlet and outlet temperature

Range = Tout – Tin

If the water enters at 27.8°C and exits at 23.61°C, then:

Range= 27.8 – 23.61= 4.19 °C

Approach is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. Although, both range and approach should be monitored, the 'Approach' is a better indicator of cooling tower performance. [14].

Approach=$T_{out}-T_{wet}$ bulb Using the mean yearly wet-bulb temperature of Ranjangaon region 25 °C

Approach= 27.8 – 25 = 2.8 °C

Cooling tower effectiveness (in percentage) is the ratio of range to the ideal range, i.e. difference between cooling water inlet temperature and ambient wet bulb temperature

$$\text{Cooling Tower effectiveness in \%} = \frac{Range}{(Range+Approach)} \times 100\%$$

$$= \frac{4.19}{4.19+2.8} \text{x}100$$

=59.9%

Cooling capacity is the heat rejected in kcal/hr or TR, Given as product of mass flow rate of water, specific heat and temperature difference.

Cooling tower flow/Cell=225 m^3/hr.

Cooling Duty Handled/Cell in kcal = Cooling tower flow/Cell x (Tout – Tin) x 1000

= 225 x (27.8– 23.61) x 1000

=942750 kcal/hr.

Evaporation Loss = 0.00085 x 1.8 x Circulation ratio(m^3/hr.) x (Tout – Tin)

= 0.00085 x 1.8 x 225 x (27.8 – 23.61)

= 1.44 m^3/hr. per Cell or Condenser

Percentage Losses = [Evaporation Loss / Cooling tower flow/Cell in m3/hr.] x 100

= [1.44 / 225] X 100

= 0.641%

Cycle of Concentration (COC) = TDS of Circulating water / TDS of Makeup water

= 2120 / 113

= 18.76

Blowdown requirement for site COC of 30.97 = Evaporation Loss / (COC - 1)

= 1.44 / (18.76 -1)

= 0.081 m^3/hr.

Makeup water requirement/cell in m3 /hr. = Evaporation Loss + Blowdown Loss

= 1.44 + 0.081

= 1.521 m^3/hr.

Heat Rejected = [Mc x C_p x (T_o – T_i)] / 3024

Mc = Mass flow rate of cooling water in Kg/hr.

C_p = Specific heat of water at kcal/kg °C.

T_i = Cooling water temperature at condenser inlet in °C.

T_o = Cooling water temperature at condenser outlet in °C.

C_p =1.0 kcal/kg at 27°C

Mc= 225000 kg/hr.

T_i = 23.61°C.

T_o = 27.8°C.

Heat Rejected = [225000 x 1.0 x (27.8 – 23.61)] / 3024

=942750/ 3024

= 311.75 TR

Difference between previous and current evaporation losses and heat rejected are as follows:

Evaporation losses before installing PHE and ETP RO Project,

Difference in evaporation loss = Before Project- After Project

= (3.786 – 1.44) m^3/hr. per cell or condenser

= 2.346 m^3/hr. per cell or condenser

We saved water consumption 2.346 m^3/hr. per cell or condenser

Percentage losses before installing PHE and ETP RO Project,

Difference in percentage losses = Before Project- After Project

= (1.683- 0.641) % per cell or condenser

= 1.042% per cell or condenser

5. CONCLUSIONS:

Use of RO water in evaporative condensers significantly improved energy efficiency and reduced makeup water consumption by 2.501m^3/hr. per cell or condenser and cooling towers, making the refrigeration plant more cost-effective and environmentally sustainable. Water Quality Stabilized Sludge removal, biological cleaning, and visual inspection of water condition led to improved clarity, reduced microbial growth, and minimized chemical dosing losses. Mechanical Reliability Enhanced Inspection and identification of corroded components (e.g., fan shafts, structure) enable proactive maintenance, extend equipment life, and reduce unexpected shutdowns. Chemical consumption reduces & cost of chemical saves due to pH maintained in range 8 to 9 & TDS maintain in sump water 10 – 2500ppm. Percentage of Hydrogen Ions (pH), Total Dissolved Solids (TDS), and Biological Oxygen Demand (BOD) meters will be installed on the condenser water sump to monitor the water parameters and automatically perform water blowdown from the condenser sump.

Table 8: Comparison table on parameters before and after completion of the project

Theoretical Parameters	Before Project	After Project
Evaporation Loss in m^3/hr. per cell	3.786 m^3/hr.	1.44 m^3/hr.
Evaporation loss in %	1.683%	0.641%

Cycle of concentration	17	18.76
Make up water requirement/cell in m^3/hr.	4.022	1.521
Heat rejected in TR	818.45 TR	311.75 TR
Blowdown Requirement m^3/hr.	0.236 m^3/hr.	0.081 m^3/hr.

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