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Experimental study of Induced Draft Cooling Tower with Evaporative Pads

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ABSTRACT
The cooling towers are used to reject the heat from the water stream to the atmosphere. With the help of the Merkel's Equation, the optimum water to air flow rate is calculated. Also, by the use of evaporative cooling pads, an additional cooling is obtained. The performance and optimization of the cooling tower is based on the cooling range and approach. To get the most energy efficient operating point of the systems, the optimization of operating conditions of cooling tower applications in cooling water is extremely significant. The objective of this paper is to compare the results derived from the existing setup of an induced draft cooling tower with the towers having evaporative cooling pads attached to it.
Keywords – Cooling Tower, Merkel Equation, Performance, Evaporative Cooling Pads.

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I. INTRODUCTION

Cooling towers originated in the 19th century through the development of condenser for use with the steam engine. Condensers use relatively cool water, via various means, to condense the steam coming out of the cylinders or turbines. This reduces the back pressure which in turn reduces the steam consumption, and thus the fuel consumption, while at the same time increasing power and recycling boiler water. However, the condensers require an ample supply of cooling water, without which they are impractical. Several evaporative methods of recycling cooling water were in use in areas lacking an established water supply, as well as in urban locations where municipal water mains may not be of sufficient supply; reliable in times of demand; or otherwise adequate to meet cooling needs. In areas with available land, the systems took the form of cooling ponds in areas with limited land, such as in cities; they took the form of cooling towers.[1]

A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of closed circuit dry cooling towers, rely solely on air to cool the working fluid to near the dry-bulb air temperature.[1]

II. COOLING TOWER TYPES

Cooling towers fall into two main categories: Natural draft and Mechanical draft. Natural draft towers use very large concrete chimneys to introduce air through the media. Due to the large size of these towers, they are generally used for water flow rates above 45,000m^3/hr. These types of towers are used only by utility power stations.[1]

Mechanical draft towers utilize large fans to force or suck air through circulated water. The water falls downward over fill surfaces, which help increase the contact time between the water and the air - this helps maximize heat transfer between the two. Cooling rates of Mechanical draft towers depend upon their fan diameter and speed of operation. Since, the mechanical draft cooling towers are much more widely used. [1]

Mechanical Draft Tower: Mechanical draft towers are available in the following airflow arrangements:
1. Counter flows induced draft.
2. Counter flow forced draft.
3. Cross flow induced draft.

In the counter flow induced draft design, hot water enters at the top, while the air is introduced at the bottom and exits at the top. Both forced and induced draft fans are used. In cross flow induced draft towers, the water enters at the top and passes over the fill. The air, however, is introduced at the side either on one side (single-flow tower) or opposite sides (double-flow tower). An induced draft fan draws the air across the wetted fill and expels it through the top of the structure. [1]

1.Problem Statement

Cooling in ordinary cooling towers involve inlet of atmospheric air from surroundings at ambient conditions, then heat is exchanged between inlet air and sprayed water resulting in cooling of water. This process is done by many ways viz. induced draft, natural draft and forced draft. However, there is still scope to increase heat transfer rate. Hence, in this dissertation, the focus is particularly on induced draft as it can be modified to get more temperature decrement than available induced draft cooling towers in market. This can be achieved by introducing evaporative cooling pads at the air inlet.

1.1Objectives

1. To design a cooling tower as per required specifications.
2. Fabrication of cooling tower and modifications according to the new concept.
3. To obtain a higher rate of heat transfer than traditionally used cooling towers.

1.2 **Scope**

1. Industrial cooling water supply Cooling towers are extensively used as cool water suppliers in various industries. Cooling towers are primarily used for heating, ventilation, and air conditioning (HVAC) and industrial purposes. Cooling towers provide a cost-effective and energy efficient operation of systems in need of cooling. Worldwide, a large number of industrial facilities use large quantities of water to cool their plants. Industrial cooling towers are larger than HVAC systems and are used to remove heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, and other industrial facilities. Cooling towers are also used in Nuclear Power Plants.

2. Commercial cooling water supply Cooling towers are common on commercial properties as part of large air conditioning systems. Cooling towers use evaporation to cool hot liquids generated by the system. Then the recovered liquids are re-circulated through the AC system. This is an effective way to cool fluids for air conditioners and make an AC system more energy efficient. Such systems are used typically in large office buildings, schools, and hospitals.

III. SELECTION OF COOLING TOWERS

The selection of cooling tower depends on many factors. An improper selected cooling tower will financially cause a loss in production due to increase in circulating water temperature and increase in electrical operating costs. Emphasis must be placed on properly specified and designed cooling towers that require minimum maintenance. To properly select a cooling tower many choices and decisions are required. The required cooling tower size and performance depends on

1. Mass flow rate of water
2. Hot water temperature
3. Cold water temperature
4. Cooling range
5. Approach to wet bulb temperature
6. Tower type
7. Materials of construction
8. Total heat rejection
9. Water quality
10. Air flow rate
11. Wet bulb temperature
12. Fill media (film, splash) [2]

IV. COMPONENTS OF A COOLING TOWER

Varieties of materials are used for constructing Cooling Tower structures. Materials like fiber glass are used for constructing package cooling towers. However, for field erected cooling towers material like steel, fibre glass, redwood and concrete and be used depending upon the project location and client preference. Plus, and minuses of each cooling tower material are given below: Wood Redwood as a material in cooling tower was used in 70’s and 80’s for small capacity cooling towers. Nowadays because of its diminishing existence wood is not used in cooling towers.[9]

The major cooling tower components include:

1. Cold Water Basin,
2. Cooling Tower Structure,
3. Fills,
4. Drift eliminators,
5. Cooling Tower Fans,
6. Water Distribution Piping’s,
7. Fan Deck & Fan cylinder,
8. Cooling Tower Louvers,
9. Valves,
10. Nozzles and
11. Electrical & Instrumentation systems.

Some of them are discussed below.

a. Fills

Although cooling tower fill is often acceptably referred to as a heat transfer surface, such terminology is not true in its strictest sense. The heat transfer surface in the classic cooling tower is actually the exposed surface of the water itself. The fill is merely a media by which more water surface is caused to be exposed to the air (increasing the rate of heat transfer), and which increases the time of air-water contact by retarding the progress of the water (increasing the amount of heat transfer).

The two basic types of fill utilized in present day cooling towers are

Splash-type — Figure 5.1(a) and

Film-type — Figure 5.1(b)

Either type of fill may be used in towers of both crossflow and counter flow configuration, positioned within the towers.[9]

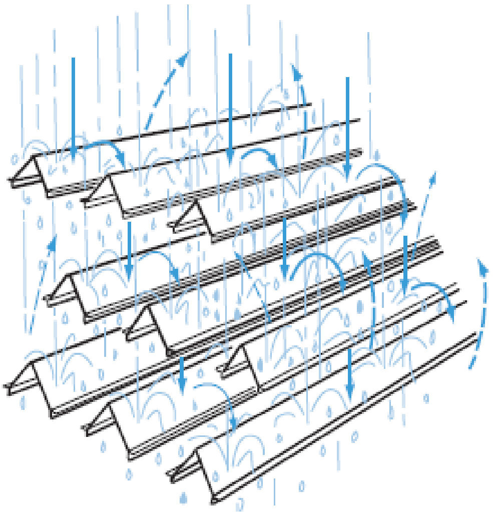

Fig.5.1(a) Splash type fills

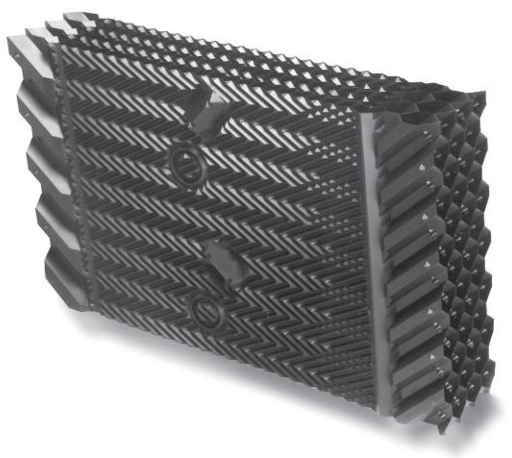

Fig 5.1(b) Film type fills

b. Drift Eliminators

The purpose of Drift eliminator is to reduce the drift loss in cooling tower. Drift eliminators normally kept next to fills in the air flow path thereby reducing the drift loss. Drift loss is the loss of entrained water through hot air to atmosphere. Drift eliminators normally made up of PVC. More number of passes through drift eliminator decreases the drift loss but increases the pressure drop thereby increasing fan power consumption.[9]

Fig5.2 Drift eliminators

c. Cooling Tower Fans

Main part of the cooling tower components. Cooling Tower fans are normally made from Aluminum, Fiber Reinforced Plastic (FRP), Glass fiber and hot-dipped galvanized steel are commonly used as fan materials. FRP being light in weight, impellers made up of FRP reduces the power requirements of the fan. Cooling tower fan blades pitch angle is varied depending on seasonal requirements. Cooling tower Fan Blade Pitch angle is the angle made by the fan with the plane. Normally during summer season, the air density is low. So the fan blade pitch angle is increased to increase the capacity of the fan. [9]

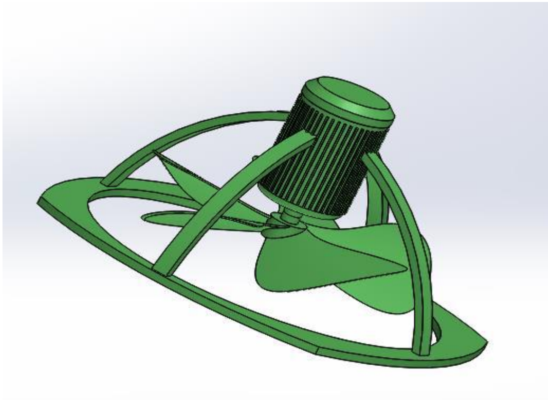

Fig.5.3 Fan

d. Evaporative Cooling Pads

Evaporative cooling is also known as adiabatic saturation of air is a thermodynamic process. When a hot and humid air passes over a wet surface, the water evaporates and air loses its sensible heat and gains equal amount of load heat of water vapor thereby reducing its temperature. The most common evaporative cooling system uses a wetted pad through which air is passed at uniform rate to make it saturated. Pads can be wetted by dripping water on upper side with help of a recirculating pump. Such a system is called direct evaporative cooling. If the incoming air is having low humidity, large quantity of water can be evaporated and large reduction in temperature can be obtained. More amount of evaporation, greater is the cooling effect. Thus the system is more efficient in hot and dry climate therefore when it is most needed.

Higher wetted surface area per unit volume gives higher efficiency as regards the material are concerned. Higher thickness increases wetted surface area to give higher efficiency for the same shape. Cooling capacities increase with mass flow rate of air indicating large mass of air being cooled but decreasing efficiency. [9]

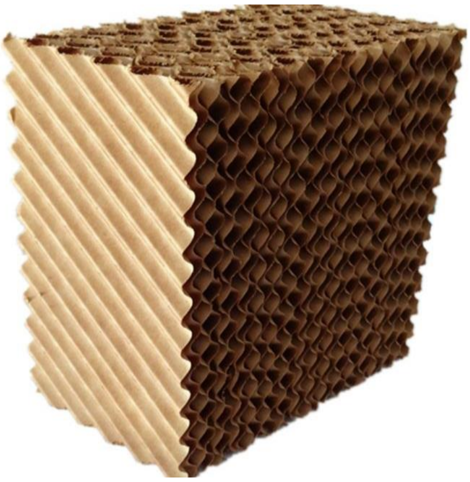

Fig. 5.4 Evaporative cooling pads

e. Nozzles

Plastics are widely used for nozzles. Many nozzles are made of PVC, ABS, polypropylene, and glass-filled nylon. Nozzles are used to provide uniform distribution of hot water inside a cell of a cooling tower. Recent advancement of the design involves a non-clogging type nozzle.[9]

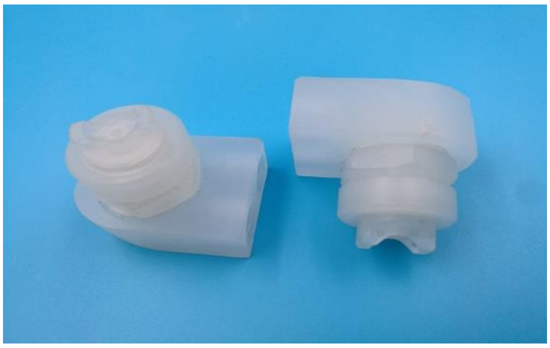

Fig 5.5 Nozzles

V. EFFCIENCY CALCULATIONS

Initially tower performance will be determined by considering anonymous range and later on it will be compared with the experimental one.

Range considered for the cooling tower is 42-36=6°C;

Where 42°C is inlet temperature and 36°C is outlet temperature.

a. Existing Setup Data

Cooling Tower Capacity – 6TR / 90000 BTUH /22679.618 Kcal/hr

Cooling tower approach (CTA)

CTA = T2 – WBT = 36 – 29.07 = 6.93 ^{0}C

Cooling tower range (CTR)

CTR = T1 – T2 = 42 – 36= 6 ^{0}C

Range °C = Heat Load in (Kcal/hour) / Water Circulation Rate in (LPH) Therefore,

Water Circulation Rate in (LPH) = Range °C/ Heat Load in (Kcal/hour) Water Circulation Rate in (LPH) = 6 / 22679.618 = 3779 LPH

Mass of water circulated in cooling tower

Mw1 = Volume of circulating water x Mass density of water

Mw1 = 3.779 x 1000

Mw1 = 3779 Kg / hr

Technical Parameter	**Quantity**
Volume of circulating water (L)	3.779 m^3/hr
Inlet temperature of water (T1)	42°C
Outlet temperature of water (T2)	36°C
Wet bulb temperature (WBT)	29.07°C
Height of the cooling tower (H)	1.524 m
Inlet temperature of air (Ta1)	35°C
Outlet temperature of air (Ta2)	41°C
Design relative humidity (ϕ)	65%

Thermal parameters	**Quantity**
Enthalpy of air at inlet temperature (Ha1)	94.92 KJ/Kg
Enthalpy of air at outlet temperature (Ha2)	73 KJ/Kg
Specific Humidity of air at inlet temperature	0.0118 Kg/Kg of
(W1)	Air
Specific humidity of air at outlet temperature	0.018 Kg/Kg of
(W2)	Air
Specific Volume of air at inlet temperature	
(Va1)	0.842 m^3/Kg
Specific volume of air at outlet temperature	
(Va2)	0.875 m^3/Kg
Enthalpy of water at inlet temperature (Hw1)	159.10 KJ/Kg
Enthalpy of water at outlet temperature	
(Hw2)	134 KJ/Kg

Heat loss by water (HL)
HL = Mw1 x Cpw x (T1 – T2)
HL = 3779 x 4.186 x (42 - 36)
HL = 94913.364 KJ / hr

Volume of air required (V)
V = (HL x Vs1) / [(Ha2 – Ha1) –{(W2 – W1) x Cpw x T2 }]
V = (94913.364 x 0.9042) / [(125.42 – 94.92) – {(0.032 – 0.023) x 4.186 x 36}]
V = 2148.28 m3 / hr

Mass of air required (Ma)
Ma = Volume of air required / Specific volume of air at inlet temperature.
Ma =V / Vs1
Ma = 2376.41 Kg/hr

Based on above data power calculation can be calculated as follows,
Fan power = Air Volume (in ACFM) X Total Pressure in inch / 6356
= 1434 X 0.6434 /6356
= 0.14515 HP
= 0.14515 X 746 watt
= 108.28 Watt.
=

b. EFFCIENCY CALCULATIONS

Range considered for the cooling tower is 38-32=6 ℃, where 38℃ is inlet temperature and 32℃ is outlet temperature.

Following equation is used to determine cooling tower efficiency which is known as the
Merkel equation,
KaV/L = [(T1 – T2) / 4] x {(1 /Δ h1) + (1 / Δ h2) + (1 / Δ h3) + (1 / Δ h4)}
Where,
K=Mass transfer co-efficient (Kg/hr m^2);
V=Active Cooling Volume (m^3);
T1=water temperature entering the cooling tower, ^{0}C;
T2=water temperature leaving the cooling tower, ^{0}C;
hw=Enthalpy of dry air at saturated water temperature (KJ/Kg of dry air);
ha=enthalpy of air, KJ/(Kg of dry air);
a=total area of wetted surface includes the surface area of water drops as well as wetted slats or other fill material, m^2;
L=water mass flow rate, Kg/s;

Now,
h1 = Value of hw - ha at T2 + 0.1 (T1 – T2)
h2 = Value of hw - ha at T2+ 0.4 (T1 – T2)
h3 = Value of hw - ha at T1 - 0.4 (T1 – T2)
h4 = Value of hw - ha at T1 - 0.1 (T1 – T2)

Calculation gives the following value for cooling tower performance

EFFICIENCY OF COOLING TOWER:

μ = (T1 – T2) / (T1 – WBT)
μ = (42 - 36) / (42- 29.07)
μ = 46. 4 %

c. Evaporative Pads Calculation

Temperature drop achievable=(DBT-WBT) x Efficiency of media
Efficiency of media = 0.9
Temperature drop achievable = (86 °F - 76.3 °F) x 0.9 = 9.72 °F
Temperature Achieved = DBT - Temperature drop achievable
= 86°F - 9.72°F =85.28°F =29 ℃
CTR = 42-34 = 8℃
CTA = 34- 26.8679 =7.14℃
Range °C = Heat Load in (Kcal/hour) / Water Circulation Rate in (LPH)
Therefore,
Heat Load in (Kcal/hour) = Range °C x Water Circulation Rate in (LPH)
Heat Load in (Kcal/hour) = 8 x 3779 =30232 Kcal/hr = 119970.272BTUH
=7.998 TR
Mass of water circulated in cooling tower
Mw1 = Volume of circulating water x Mass density of water
Mw1 = 3.779 x 1000
Mw1 = 3779 Kg /hr.
Heat loss by water (HL)
HL = Mw1 x Cpw x (T1 – T2)
HL = 3779 x 4.186 x (42 - 34)
HL = 126551 KJ / hr
Volume of air required (V)
V = (HL x Vs1) / [(Ha2 – Ha1) –{(W2 – W1) x Cpw x T2 }]
V = (126551x 0.8876/ [(159.258 – 87.058) – {(.0462 – 0.0216) x 4.186 x 32}] V = 1641.22 m^3 /hr
Mass of air required (Ma)
Ma = Volume of air required / Specific volume of air at inlet temperature Ma =V / Vs1
Ma = 1849.05 Kg / hr
Based on above data power calculation can be calculated as follows,

Fan power = Air Volume (in ACFM) X Total Pressure in inch / 6356
= 965 X 0.6434 /6356
= 0.097 HP
= 0.097 X 746 watt
= 72.87 watt

d. Effciency calculations:

Range considered for the cooling tower is 8℃
where 38℃ is inlet temperature and 32℃ is outlet temperature.
Calculation gives the following value for cooling tower performance

Efficiency of cooling tower:

μ = (T1 – T2) / (T1 – WBT)
μ= (42 - 34) / (42- 26.87)
μ= 52. 87 %

To achieve the required heat transfer rate with the evaporative cooling pads (ECP), a cooling tower with a capacity of 6TR was selected. The existing setup without the evaporative pads gave us an output of 47.7% at inlet temperature of water at 42℃ and outlet temperature of water at 36℃ with an approach of 6.6℃.

The ECP increases the humidity along with the specific heat. After adding to the existing setup, the inlet air conditions were changed from 35℃ to 30℃. The ECP gave us an increased heat transfer rate compared to the existing setup.

e. Water Distribution

The location of counter flow nozzles and the potential for poor quality circulating water demands that the nozzle system be designed to minimize fouling. The nozzle must be capable of providing uniform distribution over a wide range of flows, without significant loss in nozzle performance. The nozzle must be capable of efficient operation while consuming a minimum of expensive pump energy. The nozzle arrangement, and the design of the tower structure in the spray chamber, is critical to provide uniform distribution to the top of the fill. The placement of the nozzles must accommodate the tower geometry and still provide even coverage for all parts of the plan area.[6]

f. Air Distribution:

Three variables control the distribution of air to the fill in a counter flow configuration. The first is the air inlet geometry. The second is called the pressure ratio. The third is the fan coverage over the eliminators. Extensive aerodynamic modelling studies have been conducted to evaluate the impact of the air inlet design on distribution, and therefore on performance. It is especially important with film fill that air flow reach the entire plan area, including the region adjacent the air entrance. Any region having significantly reduced air flow will effectively allow a bypass of hot water to the cold water basin.[6]

VI. WHY EVAPORATIVE COOLING?

1. Evaporative coolers do not use compressors, condenser, chiller coils, cooling towers or heavily insulated piping. Thus the cost of acquisition and operation is a fraction of conventional air conditioning and mechanical refrigeration systems. [6]
2. Initial cost is less than 1/2 the cost of refrigerated air conditioning and the operating costs is less than 1/3rd the cost of refrigerated air conditioning to run. Maintenance costs are minimal requiring simpler procedures and lower skilled maintenance people.[6]
3. It lowers effective temperature - the temperature you feel - by at least an additional 4º to 6º. In some cases, the temperature will be lowered more, depending on relative humidity. The rapid motion of cool air increases skin surface evaporation resulting in body heat loss.[6]

ASHRAE Handbook, 1995, chapter 47, Evaporative Air Cooling notes "*dry bulb temperature reduction due to the evaporation of water always results in a lower effective temperature, regardless of the relative humidity level" and that ". Evaporative cooling can provide relief cooling of factories almost regardless of geographical location*."[7]

4. It reduces radiated heat- The constant flow of cool air absorbs heat from all exposed surfaces and results in a reduction of the heat radiated to the human body. [6]

VII. RESULTS

Parameter	Existing Setup	New Setup
Tower Height	1.52m	1.52
Fan Power	108.28	72.87
Fan CFM	1464	965
Cold Water Basin	100litres	100litres
Fills	15x30cm	15x30cm
Evaporative Pads	30.5x60cm	30.5x60cm
Pipe	ɸ1.27cm	ɸ1.27cm
Pump Head	6-20m	6-20m
Pump Flow Rate	45-46lpm	45-46lpm
Nozzle (2 nos.)	.25lps	.25lps
Efficiency	46.4%	52.6%

VIII. CONCLUSIONS

The described study allows site-specific scenario calculations for the possible development of water temperatures and the related impacts on the power plant cooling system: these are e.g. cooling water temperature, heat discharge or additional operation costs due to high temperatures and low water levels. Therefore, the model will provide a basis for site-specific adaptation measures.

1. Temperature inversions reduce a particular natural draft wet cooling tower heat rejection by approximately 20% in winter and by approximately 8% in summer.
2. The reduction in tower performance due to the adversely affected pressure differential on the outside of the tower, during temperature inversions, accounts for approximately 20% of the total loss and the increased effective inlet temperature (transfer process) for approximately 80% of the reduction in tower performance.
3. The new model shows an increased efficiency and requires lesser power input. Also, cooling capacity increased significantly.

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