Experimental Analysis on Performance of a Forced Draft and Natural Draft Counter Flow Cooling Tower

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***Abstract*— Cooling towers play an important role in industrial processes and HVAC systems by dissipating waste heat into the atmosphere. There are various heat and mass transfer mechanisms between water and air flow inside cooling tower. The experiment was conducted on a constant mass of water circulated the cooling tower, an inlet temperature of water and inlet wet bulb temperature. In this paper, we compared performance analysis of a forced draft counter flow cooling tower and the natural draft counter flow cooling tower. This paper shows that the efficiency of a forced draft counter flow cooling tower is higher than the natural draft counter flow cooling tower. Evaporation losses and blow down losses are high in a forced draft counter flow cooling tower as compared to the natural draft counter flow cooling tower.**

Keywords— Cooling tower, Wet Bulb Temperature, Cooling tower Performance, forced draft counter flow cooling tower, natural draft counter flow cooling tower, Different types of losses

I. Introduction

A cooling tower is an apparatus which transfers heat from a circulating water stream to the atmospheric air by sensible heat transfer and evaporative cooling. Cooling towers use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature. Cooling towers are able to lower the water temperatures more than devices that use only air to reject heat, like the radiator in a car, and are therefore more cost-effective and energy efficient.
Now a day’s mechanical draft cooling towers are used in majority of cases due to their less space requirements. They find main application in Refrigeration and Air Conditioning, oil industries etc.
Water is evenly distributed over the packing by nozzles at top of the tower. Water flow and temperatures can be measured and controlled with suitable equipments. A water drain tank at the bottom enables to get the exact evaporation loss.

Working Principle:

All the cooling towers are working on the principle of water evaporation. On evaporation of water, both heat and mass transfer take place, and water gets cooled. Rate of evaporation is increased by increasing air velocity. In the case of cooling tower, we call this an air draft. This air draft is created by a mechanical system of power-driven fans at the bottom of the cooling tower by using a blower. Hot water is sprayed into the tower by using specially designed spray nozzles. Water will evaporate till air in contact with it gets saturated with moisture. Thus, total evaporation will depend upon the moisture holding capacity of air, which depends on humidity. When hot water is sprayed from top of the cooling tower through our nozzles and air is made to contact from the area surrounding each nozzle. Air and water travel in co current direction down to the basin. During this travel, air cools down the water to desired temperature, and escapes through louvers at the top exit.

Types of cooling tower:

Cooling towers can be classified in two types:

a) Natural Draught Cooling Tower:

Natural-draft cooling towers use the buoyancy of the exhaust air rising in a tall chimney to provide the draft. Warm, moist air naturally rises due to the density differential to the dry, cooler outside air. Counter intuitively, more moist air is less dense than drier air at the same temperature and pressure. This moist air buoyancy produces a current of air through the tower. In this type of cooling tower, fan is not used for circulating air but here, by enclosing the heated air in the chimney and it will create pressure difference between heated air and surrounding air. Because of this pressure difference air enters into the cooling tower. It requires large hyperbolic tower, so capital cost is high but operating cost is low because of absence of electrical fan.

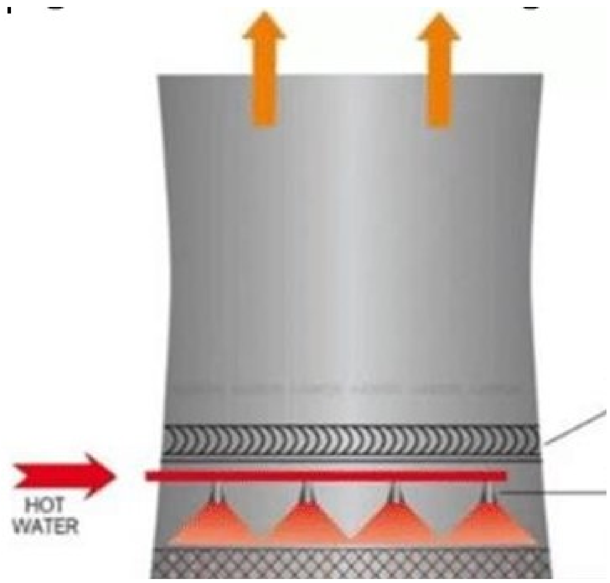

Fig.1 Natural draft cooling tower

Some characteristics of natural draft towers below:

1. Natural draft cooling towers rely on stack effect that allows the air movement on density differential. Many early designs just rely on prevailing winds to generate the draft of air.
2. Natural draft cooling towers are characterized by distinct shape much like a tall cylinder with a tight belt around the waist to provide stability
3. Such towers have the advantage of not requiring any fans, motors, gearboxes, etc. The tall stack insures against re-circulation of air
4. These towers use large space. Due to the tremendous size of these towers (500 ft high and 400 ft in diameter at the base) they are generally used for water flow rates above 200000 gal /min. These types of towers are generally used by utility power stations.

b) Mechanical or Forced Draught Cooling Tower:

Mechanical draft cooling towers use power driven fan motors to force or draw air through the circulating water. In forced draft cooling towers, air is "pushed" through the tower from an inlet to an exhaust. A forced draft mechanical draft tower is a blow-through arrangement, where a blower type fan at the intake forces air through the tower. When power plant runs on peak load; it requires a very high rate of cooling water. To rotate the fan, it uses motor with speed around 1000 rpm. Working principle is same as a natural draught cooling tower, only difference is that here fan is mounted on the cooling tower. So, forced draught cooling tower contains horizontal shaft for the fan and it is placed at bottom of the tower and the induced draught cooling tower contains vertical shaft and it is placed at top of the cooling tower.

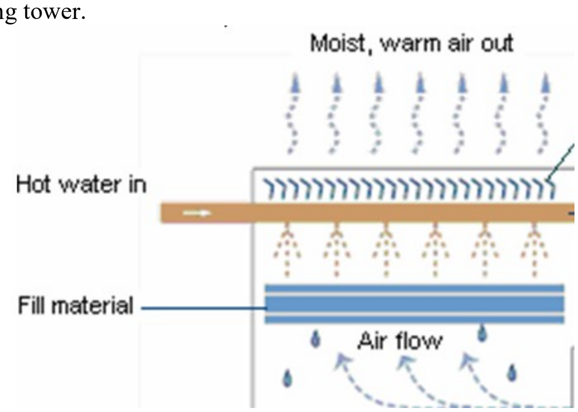

Fig.2 Forced draft cooling tower.

The forced draft cooling towers have certain disadvantages:

1. The blower forces outside air into the tower creating high entering and low exiting air velocities. The low exiting velocity of warm moisture laden air has the tendency to get re-sucked by the blower fan. This increases the apparent wet bulb temperature, and the cooling tower ceases to give the desired approach.
2. A Forced draft Cooling Tower can only be square or rectangular shaped. Forced draft arrangement always has a fan on the side. Due to this the cooling tower cannot be bottle shaped. Further, due to this characteristic, the water distribution system cannot be that of a sprinkler form. This results in inefficient water distribution.
3. It is difficult to maintain this type of a cooling tower because of the inaccessibility of the fills. Cold water basin is covered and difficult to access.
4. Pressurized upper casing is more susceptible to water leaks than the induced draft styles.
5. A forced draft design typically requires more motor horsepower typically double that of a comparable induced draft counter-flow cooling tower.

The important parameters, from the point of determining the performance of cooling towers, are:

1**(a) Range**

This is the difference between the cooling tower water inlet and outlet temperature. A high CT Range means that the cooling tower has been able to reduce the water temperature effectively, and is thus performing well.

Range (°C) = CW inlet temp – CW outlet temp

1(b) Approach

This 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.

Approach (°C) = CW outlet temp – Wet bulb temp

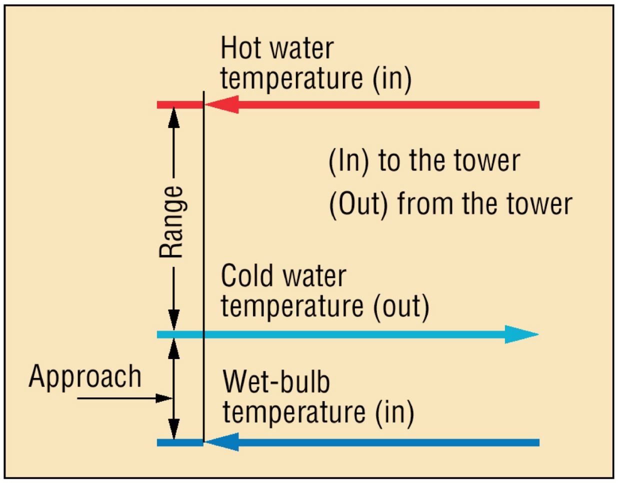

Fig.3 Temperature relationship between water and air in counter flow cooling tower

1(c) cooling tower efficiency (%)

This is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature.

Efficiency in % = Range / (Range + Approach)

1(d) Evaporation loss:

It is the water quantity evaporated for cooling duty and, theoretically, for every 10,00,000 kCal heat rejected, evaporation quantity works out to 1.8 m^3.

$$EL = 0.00085 \times M_{w1} \times (T_1 - T_2)$$

1(e) Cycles of concentration (C.O.C)

It is the ratio of dissolved solids in circulating water to the dissolved solids in makeup water.

1(f) Blow down losses

Depend upon cycles of concentration and the evaporation losses and is given by relation

Blow Down = Evaporation Loss / (C.O.C. – 1)

II Experimental setup:

Experimental set up is shown in figure. It consists mainly of a cooling tower (1) which represents the main device used in this test, a cold water basin (2), a storage tank (3) ,Geyser to provide hot water (4), a water pump (5),a flow meter device (6), Auxiliaries items are also used such as temperatures and pressures measuring devices (7) ,Tower Size : Cross Section 0.3m x 0.35m Height - 1.2m (8),Centrifugal Blower(9).

Initiating the circulation of a water flow, and lighting the electrical heaters at the same time. As soon as the temperature of feed water exceeds few degrees the desired temperature, air is injected by switching on the blower. After a few moments, the temperature of water decreases and passes again by its initial value (set point) which corresponds to the inlet water temperature at which the measurements of the dry and wet bulb temperatures of the air at the entry and the exit of the tower and the inlet and outlet water temperatures were made. Before recording any data, the system must be allowed to the steady state conditions.

Warm water is pumped from the lead tank through the control valve and water flow meter where its rate is measured and arrive to the top of the tower. After its temperature (T_1) is measured, the water is uniformly distributed over the packing elements and exposed to the air stream. During its downward passage through the packing, the water is cooled largely by evaporation of a small portion of the total flow. The cooled water falls from the packing into the basin, where its temperature (T_2) is again measured.

Fig.4 Experimental setup of Counter flow cooling tower

TABLE 1: Technical Specification for forced draft counter flow tower

Mass of water circulated in cooling tower	750 Kg/ hr
Inlet temperature of water (T_1)	35 ^{0}C
Outlet temperature of water (T_2)	22.5 ^{0}C
Cooling range	12.5 ^{0}C
Wet bulb temperature (WBT)	20 ^{0}C
Height of cooling tower (H)	1.2 m
Material of pipe used for water flow	S.S
Inlet temperature of air (T_{a1})	26^{0}C
Outlet temperature of air (T_{a2})	36 ^{0}C
Design relative humidity (Φ)	57.89 %

TABLE 2: Data from Psychometric Chart and Steam Table

Enthalpy of air at inlet temperature (H_{a1})	57.20 KJ/Kg
Enthalpy of air at outlet temperature (H_{a2})	94 KJ/Kg
Specific Humidity of air at inlet temperature (W_1)	0.01219 Kg/Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.022 Kg/Kg of air
Specific Volume of air at inlet temperature (V_{s1})	0.8642m^3/Kg
Specific Volume of air at outlet temperature (V_{s2})	0.91 m^3/Kg
Enthalpy of water at inlet temperature (H_{w1})	146.62.3KJ/Kg
Enthalpy of water at outlet temperature (H_{w2})	94.36 KJ/Kg

Calculation

•Cooling tower approach = T_2 – WBT
=22.5 – 20
=2.5 ^{0}C
•Cooling tower range = $T_1 - T_2$
=35 – 22.5
=12.5 ^{0}C
•Mass of water circulated in cooling tower

$$M_{w1} = 750 \text{ Kg / hr}$$

•Heat loss by water (HL) = M_{w1} x C_{pw} x ($T_1 - T_2$)
=750x 4.186 x (35 – 22.5)
=39243.75 KJ / hr
•Volume of air required = (HL x V_{s1}) / [($H_{a2} - H_{a1}$) - ($W_2 - W_1$) x C_{pw} x T_2]
= (39243.75 x 0.8642) / [(94 – 57.20) – (0.022 – 0.01219) x 4.186x 22.5]
= 945.32 m^3 / hr
•Heat gain by air = V x [($H_{a2} - H_{a1}$) - ($W_2 - W_1$) x C_{pw} x T_2] /V_{s1}
= 945.32x [(94 – 57.20) – (0.022 – 0.01219) x 4.186 x 22.5]/ 0.8642
=684159.833 /0.908
=753480 KJ / hr
•Mass of air required = V / V_{s1}
=945.32 /0.8642
= 1093.42 Kg / hr

Different Types of Losses:

•Drift losses = 0.20 x m_{w1} / 100 = 0.20 x 750 / 100
= 1.5 Kg / hr
•Windage losses = 0.005 x m_{w1} = 0.005 x 750
= 3.75 Kg / hr
•Evaporation losses = 0.00085 x m_{w1} x ($T_1 - T_2$) = 0.00085 x 750 x (35 – 22.5)
= 7.97 Kg / hr
•Cycles = XC / XM
M = WL + EL + DL = 3.75 + 7.97 + 1.5 = 13.22 Kg / hr
XC / XM = M / (M - EL) = 13.33 / (13.22 – 7.97)
XC / XM = Cycles = 2.52
•Blow down losses = EL / (Cycles - 1)
=7.96 / (2.52 - 1)
=5.25 Kg / hr
•Efficiency of cooling tower
=($T_1 - T_2$) / (T_1 – WBT)
=(35-22.5) / (35-20)
=83.33%

TABLE 3: Technical Specification for natural draft counter flow tower

Mass of water circulated in cooling tower	750 m^3/ hr
Inlet temperature of water (T_1)	35 ^{0}C
Outlet temperature of water (T_2)	27 ^{0}C
Cooling range	8 ^{0}C
Wet bulb temperature (WBT)	20 ^{0}C
Height of cooling tower (H)	1.2 m
Material of pipe used for water flow	S.S
Inlet temperature of air (T_{a1})	26^{0}C
Outlet temperature of air (T_{a2})	32 ^{0}C
Design relative humidity (Φ)	57.89 %

TABLE 4**:** Data from Psychometric Chart and Steam Table

Enthalpy of air at inlet temperature (H_{a1})	57.20 KJ/Kg
Enthalpy of air at outlet temperature (H_{a2})	76.10 KJ/Kg
Specific Humidity of air at inlet temperature (W_1)	0.01219 Kg/Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.017 Kg/Kg of Air
Specific Volume of air at inlet temperature (V_{s1})	0.8642m3/Kg
Specific Volume of air at outlet temperature (V_{s2})	0.885 m3/Kg
Enthalpy of water at inlet temperature (H_{w1})	146.62.3 KJ/Kg
Enthalpy of water at outlet temperature (H_{w2})	113.18.36KJ/Kg

Calculation

•Cooling tower approach = T_2 – WBT
=27 – 20
=7 ^{0}C
•Cooling tower range = $T_1 - T_2$
=35 – 27
=8 ^{0}C
•Mass of water circulated in cooling tower

$$M_{w1} = 750 \text{ Kg / hr}$$

•Heat loss by water (HL) = M_{w1} x C_{pw} x ($T_1 - T_2$)
=750x 4.186 x (35 – 27)
=25116 KJ / hr
•Volume of air required = (HL x V_{s1}) / [($H_{a2} - H_{a1}$) - ($W_2 - W_1$) x C_{pw} x T_2]
= (25116 x 0.8642) / [(76.1 – 57.20) – (0.017– 0.01219) x 4.186x 27]
= 1182.83 m^3 / hr
•Heat gain by air = V x [($H_{a2} - H_{a1}$) - ($W_2 - W_1$) x C_{pw} x T_2] /V_{s1}
= 1182.43x [(76.1 – 57.20) – (0.017– 0.01219) x 4.186 x 27] / 0.8642
=10878.356 KJ / hr
•Mass of air required = V / V_{s1}
=1182.43 /0.8642
= 1368.2 Kg / hr

Different Types of Losses:

•Drift losses = 0.20 x m_{w1} / 100 = 0.20 x 750 / 100
= 1.5 Kg / hr
•Windage losses = 0.005 x m_{w1} = 0.005 x 750
= 3.75 Kg / hr
•Evaporation losses = 0.00085 x m_{w1} x ($T_1 - T_2$) = 0.00085 x 750 x (35 – 27)
= 5.1 Kg / hr
•Cycles = XC / XM
M = WL + EL + DL = 3.75 + 5.1 + 1.5 = 10.35 Kg / hr
XC / XM = M / (M - EL) = 10.35 / (10.35– 5.1)
XC / XM = Cycles = 1.99
•Blow down losses = EL / (Cycles - 1)
=5.1 / (1.99 - 1)
=5.15Kg / hr

•Efficiency of cooling tower
$= (T_1 - T_2) / (T_1 - WBT)$
$= (35-27) / (35-20)$
$=53.33\%$

III. Result and Discussion:

Sr.No.	Parameter	Counter flow cooling tower	
		Forced draft	Natural draft
1	Range	12.5	8
2	Approach	2.5	7
3	Efficiency of cooling tower	83.3%	53.3%
4	Heat loss by water	39243.7 KJ/hr	25116 KJ/hr
5	Mass of air	1093.86 Kg/hr	1182.43 Kg/hr
6	Drift losses	1.5 Kg / hr	1.5 Kg / hr
7	Evaporation loss	7.97 Kg / hr	5.1Kg / hr
8	Blow down losses	5.25 Kg / hr	5.15 Kg / hr

The efficiency of forced draft counter flow cooling tower is 83.3 % and the efficiency of natural draft counter flow cooling tower is 53.3 %. The efficiency of forced draft counter flow cooling tower is higher than natural draft counter flow cooling tower. Evaporation losses and blow down losses are high in forced draft counter flow cooling tower as compare to natural draft counter flow cooling tower. The comparative analysis shows that the choice of the cooling tower type depends on the specific requirements of the thermal power plant. For example, if water availability is a concern, the natural draft cooling tower may be preferred over the forced draft cooling tower. On the other hand, if maximizing cooling efficiency is a priority, the forced draft cooling tower may be the better option.

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