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Experimental Analysis on Performance of a Counter Flow Tray Type Cooling Tower

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Abstract: ***The main aim of this project is to increase the cooling rate by modifying the design i.e by replacing the fill material with the aluminum trays and reducing the height to provide an energy efficient. In this, use trays for the water to move horizontally in each tray and get a large surface area for the water to evaporate. Thus the height of the tower is reduced by use tray type. This cooling tower is counter-flow type. Thus understand the basic principles of cooling tower operation, types of cooling tower, various components used in cooling tower, the factors affecting the cooling tower performances and energy saving opportunities in cooling tower. A general study was made on the design consideration of cooling tower, importance of energy balance and mass balance while designing the cooling tower, influence of Wet bulb temperature in cooling tower performance, applicability of Psychometric chart in cooling tower design & formulas used for designing the cooling towers and performance calculations. The performance of counter flow tray type cooling tower such as efficiency, losses results were compared with the fill material bottle type cooling tower and also investigating the performance of counter flow tray type cooling tower in different seasons.***

Keywords: Cooling tower, Wet Bulb Temperature, Cooling tower Performance, Bottle type Cooling tower, Tray type Cooling tower, Thermal Design, Different types of losses.

1. Introduction

Cooling water is used to condense steam in a condenser or to cool process liquid in any heat exchanger etc. This cooling water gets warmed up when it is passed through the condenser tubes or heat exchanger tubes for cooling. This water that got warmed up is cooled in the cooling tower, so that it can be recycled again.

Cooling tower is a heat rejection device that transfers waste heat from a process to the atmosphere though the cooling of the recalculated water flow. The type of heat rejection is commonly named as "evaporative cooling".

The humidity is defined as water particles present in atmospheric air. The specific humidity is the major factor in the atmosphere, it depends upon atmospheric temperature.

A cooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. It is a concrete structure, steel or wooden and corrugated surfaces or baffles or perforated trays are provided inside the tower for uniform distribution and better atomization of water in the tower.

There are number of factor affecting the performance of cooling tower like inlet temperature of water and air, outlet temperature of water and air, porosity in fills, speed of fan, mass flow rate of air and water. For increase the efficiency of cooling tower need to be optimizing this parameter.

Cooling towers are used in facilities where process cooling is required in order to dissipate the heat that is created as a result of the process application, oil refining, including power generation, steel mills, pulp and paper plants, chemical processing and more. Cooling Towers are also a necessary component of the HVAC systems used to heat and cool large commercial buildings or server rooms.

2. Working Principle

When water comes into contact with air, a portion of the water evaporates depending on the humidity of the air. The ***Latent Heat*** of evaporation is taken from the main stream of water itself. Because of this, the main stream of water gets cooled.

Dry Bulb temperature is the temperature measured, when the bulb of the thermometer is freely exposed to the atmosphere. ***Wet Bulb*** temperature is the lowest temperature that can be reached by the evaporation of water only [3]. This is usually measured by having a moist cloth or wick in the bulb of the thermometer and allowing the moisture to evaporate in a moving air stream.

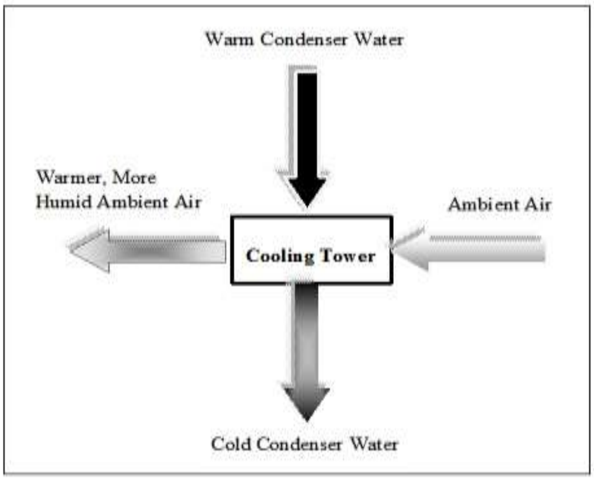

Figure 1: Working principle of cooling tower

The difference between the wet bulb and dry bulb temperatures is the driving force for the water to evaporate. And this difference in temperature is the one that decides the efficiency of the tower. In the cooling tower, the warm water is sent to the top of the cooling tower and it is allowed to flow down in the cooling tower. Atmospheric air is sent from bottom to top. Thus the water comes into contact with the air that is moving upwards. This air and water have intimate contact.

During this contact, some of the water evaporates and moves from liquid phase to vapour phase. The heat required for the evaporation of this water is given up by the main body of water as it flows through the cooling tower. In other words, the vaporization of this small portion of water provides the cooling for the remaining un-evaporated water that is flowed through the cooling tower.

The heat from the water stream gets transferred to the air stream and the temperature of the air increases. Also, the relative humidity of the air increases to 100%. This air is discharged into the atmosphere by a fan. The quantity of water that evaporates depends on the humidity of the air it comes across.

3. Cooling Tower Performance

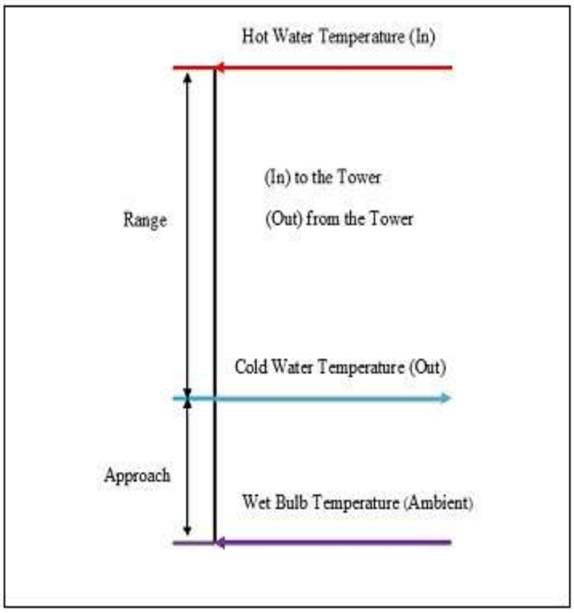

Figure 2: Range and Approach of Cooling Tower

3.1 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 [1].

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

3.2 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 [1].

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

3.3 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 [3].

Efficiency in % = Range / (Range + Approach)

3.4 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 x mw1 x (T1 – T2)

3.5 Cycles of concentration (C.O.C)

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

3.6 Blow down losses

Depend upon cycles of concentration and the evaporation losses and is given by relation [4].

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

4. Factors Affecting Cooling Tower Performance

4.1 Capacity

Heat dissipation (in kCal/hour) and circulated flow rate (m3/hr) are not sufficient to understand cooling tower performance. Other factors, which we will see, must be stated along with flow rate m3/hr [5].

4.2 Heat Load

The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature level of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product. In some applications (e.g. internal combustion engines), however, high operating temperatures are desirable.

4.3 Wet Bulb Temperature

Wet bulb temperature is an important factor in performance of evaporative water cooling equipment. It is a controlling factor from the aspect of minimum cold water temperature to which water can be cooled by the evaporative method. Thus, the wet bulb temperature of the air entering the cooling tower determines operating temperature levels throughout the plant, process, or system. Theoretically, a cooling tower will cool water to the entering wet bulb temperature, when operating without a heat load.

5. Bottle Type Cooling Tower

Figure 3: Bottle Type Cooling Tower

The tower design incorporates hot water inlet at the bottom collection sump circulated vertically to the mechanical rotary sprinkler located above the fill media [6]. The inlet water pressure rotates the sprinkler, having extended arm pipes with orifices to disperse water uniformly over the fill media [6].

The fan directly coupled to the motor, during operations takes away the heat by induced draft mechanism [6]. Air is drawn from the lower air intake area & is induced to travel through the fill media thus taking away the latent heat from the water passing through the fill media. Portion of water evaporated, removes the heat from the remaining water [6].

Table 1: Technical Specification

Volume of circulating water (V)	30 m^3/ hr
Inlet temperature of water (T_1)	39^0C
Outlet temperature of water (T_2)	33^0C
Cooling range	6^0C
Wet bulb temperature (WBT)	29^0C
Height of cooling tower (H)	2.4 m
Material of pipe used for water flow	S.S
Inside diameter of pipe (d_i)	0.10 m
Outside diameter of pipe (d_o)	0.12 m
Inlet temperature of air (T_{a1})	35^0 C
Outlet temperature of air (T_{a2})	42^0 C
Design relative humidity (Φ)	65 %

Table 3: Data from Psychometric Chart and Steam Table

Enthalpy of air at inlet temperature (H_{a1})	94 KJ/Kg
Enthalpy of air at outlet temperature (H_{a2})	118 KJ/Kg
Specific Humidity of air at inlet temperature (W_1)	0.024 Kg/Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.03 Kg/Kg of air
Specific Volume of air at inlet temperature (V_{s1})	0.908 m^3/Kg
Specific Volume of air at outlet temperature (V_{s2})	0.94 m^3/Kg
Enthalpy of water at inlet temperature (H_{w1})	163.3 KJ/Kg
Enthalpy of water at outlet temperature (H_{w2})	138.2 KJ/Kg

5.1 Calculation

- Cooling tower approach = T_2 – WBT
= 33 – 29
= 4^o C

- Cooling tower range = $T_1 – T_2$
= 39 – 33
= 6^o C

- Mass of water circulated in cooling tower
M_{w1} = Volume of circulating water x Mass density of water
M_{w1} = 30 x 1000
M_{w1} = 30000 Kg / hr

- Heat loss by water (HL) = M_{w1} x C_{pw} x ($T_1 – T_2$)
= 30000 x 4.186 x (39 - 33)
= 753480 KJ / hr

- Volume of air required = (HL x V_{s1}) / [($H_{a2} – H_{a1}$) - ($W_2 – W_1$) x C_{pw} x T_2]
= (753480 x 0.908) / [(118 - 94) – (0.03 – 0.024) x 4.186 x 33]
= 29526.337 m^3 / hr

- Heat gain by air = V x [($H_{a2} – H_{a1}$) - ($W_2 – W_1$) x C_{pw} xT_2] / V_{s1}
= 29526.337 x [(118 - 94) – (0.03 – 0.024) x4.186 x 33] / 0.908
= 684159.833 /0.908
= 753480 KJ / hr

- Mass of air required = V / V_{s1}
= 29526.337 /0.908
= 32517.992 Kg / hr

Different Types of Losses:

- Drift losses = 0.20 x m_{w1} / 100
= 0.20 x 30000 / 100
= 60 Kg / hr

- Windage losses = 0.005 x m_{w1}
= 0.005 x 30000
= 150 Kg / hr

- Evaporation losses = 0.00085 x m_{w1} x ($T_1 – T_2$)
= 0.00085 x 30000 x (39 - 33)
= 153 Kg / hr

- Cycles = XC / XM
M = WL + EL + DL = 150 + 153 + 60
= 363 Kg / hr
XC / XM = M / (M - EL) = 363 / (363 - 153)
XC / XM = Cycles = 1.7286

- Blow down losses = EL / (Cycles - 1)
= 153 / (1.7286 - 1)
= 210 Kg / hr
- Efficiency of cooling tower
= ($T_1 – T_2$) / (T_1 – WBT)
= (39-33) / (39-29)
= 60%

6. Counter Flow Tray Type Cooling Tower

Figure 4: Counter Flow Tray Type Cooling Tower

6.1 Construction Method

Four L angles (185cm each) mounted vertically, with two sets of cross bars connected horizontally to keep them in place. The structure was made to have 57 cm in length and 54 cm in width. In the bottom portion of the tower space was kept to house the sump.

Several holes were drilled in the workshop on the vertical L angles at space interval of 14 cms to fix the trays. The aluminium sheet was cut to have the dimension of ~ 57 cms x 37 cms. Aluminium beedings were affixed and nailed into the cut sheets, so that the tray can hold water.

On the top of the tower 4 cross bars were screwed horizontally to house the Induced draft fan. The fan was mounted on the top of these cross bars using screws. The draft fan is placed on the top of the cooling tower.

The sump was inserted into the bottom portion of the tower. Provision was made to hold the thermometer in the sump. The pump was fixed in a plywood sheet base. Suction hose was connected in the pump via a reducer nipple. The pump is placed on the bottom of the cooling tower.

The downstream of the ball valve was connected to an 1” x ½” hose and the hose was connected to the heater. The heater outlet was connected to the distributor via a Tee.

A distributor is installed on top of the first tray. This is made up of 0.5” diameter PVC pipe with 20 holes of 4mm diameter drill into it. The holes are evenly spread across its length. This ensures uniform distribution of water spray horizontally in the top tray. Water flow from the distributor was measured and the valve at the pump discharge was adjusted to get 13 litres per minute of water.

A thermometer is installed in the Tee with a cork to measure the outlet temperature of the heater (inlet temperature of water to the tower).

Mild steel L angles were cut as per the required sizes and installed in the tower at appropriate locations. Trays were placed in each of these trays one below the other, so that outlet of one tray falls on the inlet of next tray. Outlet from the last tray falls into the sump.

The pump was primed and started and the water flow at the outlet was adjusted using the ball valve. The water flow at the discharge was measured for a fixed interval of time. The ball valve was finally adjusted to get a flow of 13 litres per minute. Initially, we need about 55 litres of water to fill the sump. Afterwards we need about 10 litres per hour to make up the evaporation loss and other losses.

6.2 Winter Season Calculations

Table 3: Technical Specification

Volume of circulating water (V)	0.849 m^3/ hr
Inlet temperature of water (T_1)	41^0C
Outlet temperature of water (T_2)	31^0C
Cooling range	10^0C
Wet bulb temperature (WBT)	27^0C
Height of cooling tower (H)	1.85 m
Inlet temperature of air (T_{a1})	32^0 C
Outlet temperature of air (T_{a2})	39^0 C
Design relative humidity (Φ)	70 %

Table 4: Data from Psychometric Chart and Steam Table

Enthalpy of air at inlet temperature (H_{a1})	83 KJ/Kg
Enthalpy of air at outlet temperature (H_{a2})	105 KJ/Kg
Specific Humidity of air at inlet temperature (W_1)	0.021 Kg/Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.029 Kg/Kg of air
Specific Volume of air at inlet temperature (V_{s1})	0.89 m^3/Kg
Specific Volume of air at outlet temperature (V_{s2})	0.93 m^3/Kg
Enthalpy of water at inlet temperature (H_{w1})	171.6
Enthalpy of water at outlet temperature (H_{w2})	129.8

- Cooling tower approach = T_2 – WBT
= 31 – 27
= 4^o C
- Cooling tower range = $T_1 – T_2$
= 41 – 31
= 10^o C

- Mass of water circulated in cooling tower
M_{w1} = Volume of circulating water x Mass density of water
M_{w1} = 0.849 x 1000
M_{w1} =849 Kg / hr

- Heat loss by water (HL) = M_{w1} x C_{pw} x ($T_1 – T_2$)
= 849 x 4.186 x (41 - 31)
= 35539.14 KJ / hr

- Volume of air required = (HL x V_{s1}) / [($H_{a2} – H_{a1}$) - ($W_2 – W_1$) x C_{pw} x T_2]
 = (35539.14 x 0.89) / [(105 - 83) – (0.029 – 0.021) x 4.186 x 31]
 = 1508.22228 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}
 = 1508.22228x [(105 - 83) – (0.029 – 0.021) x4.186 x 31] / 0.89
 = 31615.16238 /0.890
 = 35539.14 KJ / hr

- Mass of air required = V / V_{s1}
 = 1508.22228 /0.89
 = 1694. 633236 Kg / hr

Different Types of Losses:

- Drift losses = 0.20 x m_{w1} / 100
 = 0.20 x 849/ 100
 = 1.698 Kg / hr

- Windage losses = 0.005 x m_{w1}
 = 0.005 x 849
 = 4.245 Kg / hr

- Evaporation losses = 0.00085 x m_{w1} x ($T_1 – T_2$)
 = 0.00085 x 849 x (41 - 31)
 = 7.2165 Kg / hr

- Cycles = XC / XM
 M = WL + EL + DL = 1.698 + 4.245 + 7.2165
 = 13.1595 Kg / hr
 XC / XM = M / (M - EL) = 13.1595 / (13.1595 – 7.2165)
 XC / XM = Cycles = 2.2143

- Blow down losses = EL / (Cycles - 1)
 = 7.2165 / (2.2143 - 1)
 = 5.9429 Kg / hr

- Efficiency of cooling tower
 = ($T_1 – T_2$) / (T_1 – WBT)
 = (41 – 31) / (41 - 27)
 = 71.429 %

6.3 Summer Season Calculations

Table 5: Technical Specification

Volume of circulating water (V)	0.78 m^3/ hr
Inlet temperature of water (T_1)	43^0C
Outlet temperature of water (T_2)	35^0C
Cooling range	8^0C
Wet bulb temperature (WBT)	30^0C
Height of cooling tower (H)	1.85 m
Inlet temperature of air (T_{a1})	36^0 C
Outlet temperature of air (T_{a2})	44^0 C

Table 6: Data from Psychometric Chart and Steam Table

Enthalpy of air at inlet temperature (H_{a1})	89 KJ/Kg
Enthalpy of air at outlet temperature (H_{a2})	120 KJ/Kg
Specific Humidity of air at inlet temperature (W_1)	0.0244 Kg/Kg of air
Specific Humidity of air at outlet temperature (W_2)	0.027 Kg/Kg of air
Specific Volume of air at inlet temperature (V_{s1})	0.912 m^3/Kg
Specific Volume of air at outlet temperature (V_{s2})	0.945 m^3/Kg
Enthalpy of water at inlet temperature (H_{w1})	180.0 KJ/Kg
Enthalpy of water at outlet temperature (H_{w2})	146.6 KJ/Kg

- Cooling tower approach = T_2 – WBT
 = 35 – 30
 = 5^o C

- Cooling tower range = $T_1 – T_2$
 = 43 – 35
 = 8^o C

- Mass of water circulated in cooling tower
 M_{w1} = Volume of circulating water x Mass density of water
 M_{w1} = 0.78 x 1000
 M_{w1} = 780 Kg / hr

- Heat loss by water (HL) = M_{w1} x C_{pw} x ($T_1 – T_2$)
 = 780 x 4.186 x (43 - 35)
 = 26120.64 KJ / hr

- Volume of air required = (HL x V_{s1}) / [($H_{a2} – H_{a1}$) - ($W_2 – W_1$) x C_{pw} x T_2]
 = (26120.64 x 0.912) / [(120 - 89) – (0.027 – 0.0244) x 4.186 x 35]
 = 778.0125447 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}
 = 1215.4338x [(120 - 89) – (0.027 – 0.0244) x4.186 x 35] / 0.912
 = 23822.02368 /0.912
 = 26120.64 KJ / hr

- Mass of air required = V / V_{s1}
 = 778.0125447 / 0.912
 = 853.0839 Kg / hr

Different Types of Losses

- Drift losses = 0.20 x m_{w1} / 100
 = 0.20 x 780 / 100
 = 1.56 Kg / hr

- Windage losses = 0.005 x m_{w1}
 = 0.005 x 780
 = 3.9 Kg / hr

- Evaporation losses = 0.00085 x m_{w1} x ($T_1 – T_2$)
 = 0.00085 x 780 x (43 - 35)
 = 5.304 Kg / hr

- Cycles = XC / XM
 M = WL + EL + DL = 1.56 + 3.9 + 5.304
 = 10.764 Kg / hr
 XC / XM = M / (M - EL) = 10.764 / (10.764 – 5.304)

XC / XM = Cycles = 1.9714

- Blow down losses = EL / (Cycles - 1)

= 5.304 / (1.9714 - 1)
= 5.460 Kg / hr

- Efficiency of cooling tower

= $(T_1 – T_2) / (T_1 – WBT)$
= (43 - 35) / (43 - 30)
= 61.538 %

7. Result

Table 7: Comparison of Counter Flow Tray Type Cooling Tower and Bottle Type Cooling Tower

Parameter	*Counter Flow Tray Type*	*Bottle Type*
Range	8˚C	6˚C
Approach	5˚C	4˚C
Efficiency of cooling tower	61.538%	60 %
Heat loss by water	26120.64 KJ / hr	753480 KJ / kg
Mass of air	853.0839 kg / hr	32517.992 kg / hr
Drift losses	1.56 kg / hr	60 kg / hr
Evaporation losses	5.304 kg / hr	153 kg / hr
Blow down losses	5.460 kg / hr	210 kg / hr

Table 8: Comparison of Counter Flow Tray Type Cooling Tower Performance in Two Varies seasons

Parameter	*Counter Flow Tray Type*	
	Winter season	*Summer season*
Range	10˚C	8˚C
Approach	4˚C	5˚C
Efficiency of cooling tower	71..429%	61.538%
Heat loss by water	35539.14 KJ / kg	26120.64 KJ / hr
Mass of air	1694.633236 kg / hr	853.0839 kg / hr
Drift losses	1.698 kg / hr	1.56 kg / hr
Evaporation losses	7.2165 kg / hr	5.304 kg / hr
Blow down losses	5.9429 kg / hr	5.460 kg / hr

The fill type material bottle cooling tower efficiency is 60 % .The counter flow tray type cooling tower efficiency is 61.538%.

The efficiency of the cooling tower is high in winter season as comparison to summer season. The efficiency of cooling tower in winter season 71.429%.Efficiency of cooling tower in summer season = 61.538% the cooling tower efficiency difference between summer season and winter season is =9.891%.

The cooling tower is closely related to different types of losses generated in cooling tower. The losses of the cooling tower are high in winter season as compare to summer season.

The performance of the counter flow tray type cooling tower is dominated by wind speed, ambient air temperatures and humidity in the atmospheric conditions. When the humidity is high in atmosphere, large quantity of water is required for cooling condensate. When humidity is low in atmosphere, small quantity of water is required for cooling condensate.

The Counter flow tray type cooling tower performance such as high efficiency and low losses compared to bottle type cooling tower.

The counter flow tray type cooling is more economically, more life time, low maintenance and performs high efficiency.

8. Conclusion

The calculation of cooling tower is closely related to tower Characteristic and different types of losses generated in cooling tower such as drift losses, evaporation losses and blow down losses can be calculated.

The fill type material bottle cooling tower efficiency is 60 % .The counter flow tray type cooling tower efficiency is 61.538%.
The performance of the cooling tower is dominated by wind speed, ambient air temperatures and humidity in the atmospheric conditions. The maintenance of cooling tower in the form of removal of scale or corrosion plays important role in the performance of the tower.

In ideal condition, the heat loss by water must be equal to heat gain by air. But in actual practice it is not possible because of some type of losses. Cooling tower performance increases with increase in air flow rate, increase in air-water contact and characteristic decreases with increase in water to air mass ratio.

The efficiency of the cooling tower is high in winter season as comparison to summer season. The efficiency of cooling tower in winter season 71.429%.Efficiency of cooling tower in summer season = 61.538% the cooling tower efficiency difference between summer season and winter season is =9.891%.. The losses of the cooling tower are high in winter season as compare to summer season.

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