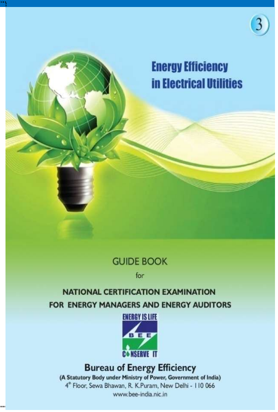
OPTC TRAINING COURSE

BOOK 3 – ENERGY EFFICIENCY IN ELECTRICAL UTILITIES
Brief Contents

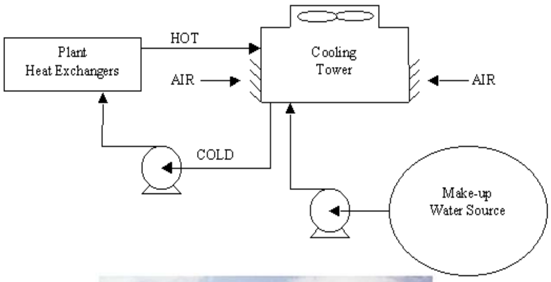


Chapter-7 Cooling Towers
Contents

7.1 Introduction

Cooling Water System

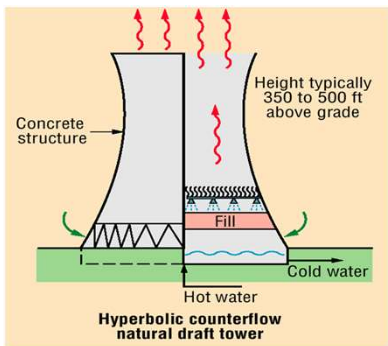
- The main task of a cooling tower is to reject heat into the atmosphere.
- It is a closed loop cooling tower system. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers. The make-up water source is used to replenish water lost to evaporation.
- Relatively inexpensive of removing low-grade heat from cooling water

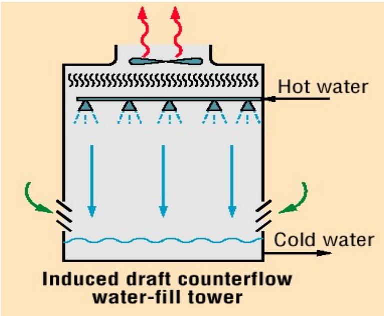


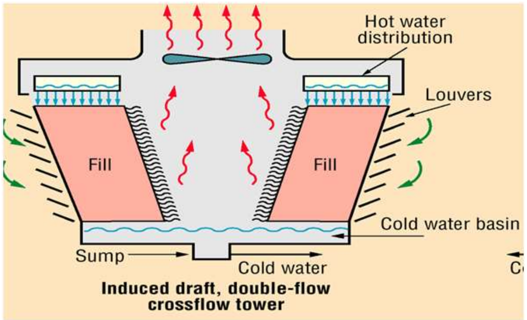
Cooling tower: Types

Two Type of main categories

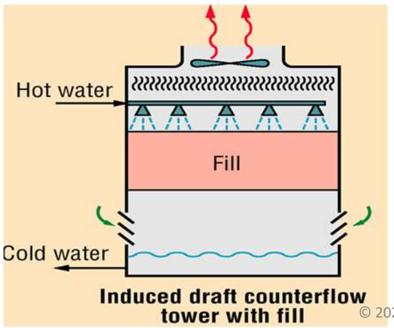
- Natural draft
  - Large concrete chimneys
  - generally used for water flow rates above 45,000 m^3/hr
  - utility power stations
- Mechanical draft
  - Large fans to force or suck air through circulated water.
  - The water falls downward over fill surfaces, which help increase the contact time between the water and the air maximising heat transfer between the two.
  - Cooling rates of Mechanical draft towers depend upon their fan diameter and speed of operation

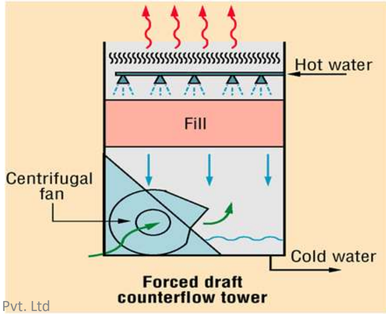






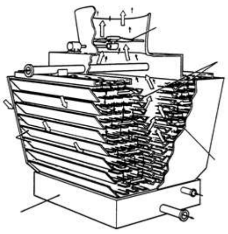
Mechanical Draft Types





Components of Cooling Tower

- **Frame and casing**
- **Fill**
- **Cold water basin**
- **Drift eliminators**
- **Air inlet**
- **Louvers**
- **Nozzles**
- **Fans**



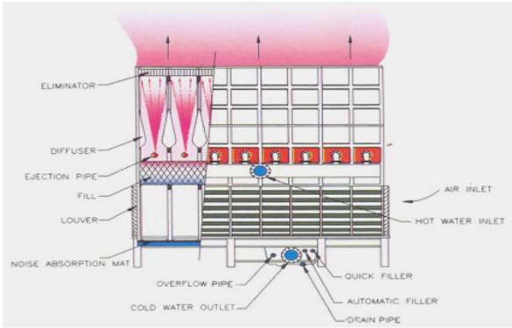
Tower Materials

- Wooden components included the frame, casing, louvers, fill, and often the cold water basin
- Galvanized steel, various grades of stainless steel, glass fiber, and concrete
  - enhance corrosion resistance, reduce maintenance, and promote reliability and long service life
- Plastics are widely used for fill, including PVC, polypropylene, and other polymers. Plastics also find wide use as nozzle materials
- Aluminum, glass fiber, and hot-dipped galvanized steel are commonly used fan materials.
- Centrifugal fans are often fabricated from galvanized steel. Propeller fans are fabricated from galvanized, aluminum, or molded glass fiber reinforced plastic

Fanless Cooling Towers

Basis of Theory

- Fanless cooling tower takes advantage of the water pressure of the existing water circulation pump forming a water screen with specially designed ejection headers.
- As the water flows through the nozzles at high velocity, based on a ejector principle, low pressure is created which sucks the ambient cold air into the tower.
- The kinetic energy of Water entering the cooling tower is converted into kinetic energy of the air by the use of specially designed ejector nozzles. Water Pressure required in the Jet Ejector Nozzles is min. 0.5 Bar.
- The incoming air passes through the fills at the bottom while the ejected water falls on the fills thus enabling a counter current heat exchange between water and air. Drift eliminators are provided to contain the drift losses.

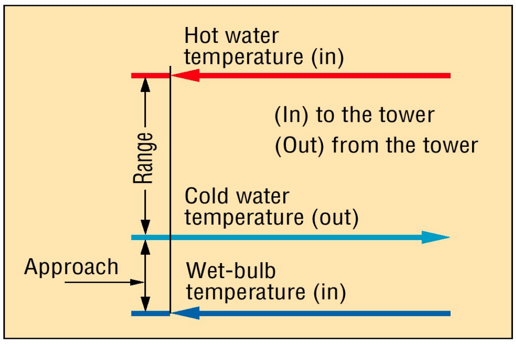


Fanless Cooling Tower

- Features of Fanless Cooling Tower
- Energy saving
- Low noise
- Water saving
- Low maintenance cost

7.2 Cooling Tower Performance

1. **"Range"** is the difference between the cooling tower water inlet and outlet temperature
2. **"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.
3. **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, or in other words it is = **Range / (Range + Approach).**
4. **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.
5. **Evaporation loss** 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. An empirical relation used often is:



Evaporation Loss(m3/hr)
= 0.00085x1.8xcirculation rate (m3/hr)x(T1-T2)

T1-T2 = Temp. difference between inlet and outlet water.

7.2 Cooling Tower Performance

6. **Cycles of concentration (C.O.C)** is the ratio of dissolved solids in circulating water to the dissolved solids in make up water.

7. **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)

Against design values, seasonal variations require adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness through measures like water box loading changes, blade angle adjustments.

8. **Liquid/Gas (L/G) ratio,** of a cooling tower is the ratio between the water and the air mass flow rates.

Where,

L/G= liquid to gas mass flow ratio (kg/kg)

T_1= hot water temperature (^{0}C)

T_2= cold water temperature (^{0}C)

h_2= enthalpy of air-water vapor mixture at exhaust wet-bulb temperature (same units as above)

h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature (same units as above)

$$L(T_1 - T_2) = G(h_2 - h_1)$$

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2}$$

Factors Affecting Cooling Tower Performance

Capacity

Heat dissipation (in kcal/hour) and circulated **flow rate** (m^3/hr) **are not sufficient to understand** cooling tower performance. Other factors, must be stated along with flow rate m^3/hr.

For example, a cooling tower sized to cool 4540 m^3/hr through a 13.9^{o}C range might be larger than a cooling tower to cool 4540 m^3/hr through 19.5^{o}C range.

Range

Range is determined not by the cooling tower, but by the process it is serving.

Range ^{o}C = Heat Load (kcal/hr)/ Water Circulation Rate in LPH

Range is a function of the heat load and the flow circulated through the system.

Cooling towers are usually specified to cool a certain flow rate from one temperature to another temperature at a certain wet bulb temperature.

For example, the cooling tower might be specified to cool 4540 m^3/hr from 48.9^{o}C to 32.2^{o}C at 26.7^{o}C wet bulb temperature.

Approach

Approach = Cold Water Temperature – Wet Bulb Temperature

As closer the approach to the wet bulb, the more expensive the cooling tower due to increased size.

Usually a 2.8°C approach to the design wet bulb is the coldest water temperature that cooling tower manufacturers **will guarantee**.

If flow rate, range, approach and wet bulb had to be ranked in the order of their importance in sizing a tower, approach would be first with flow rate closely following the range and wet bulb would be of lesser importance.

Factors that affect cooling tower size

Cooling tower size is affected by the heat load, range, approach, and WBT. When three of these four quantities are held constant, tower size varies in the following manner:

- Directly with the heat load
- Inversely with the range
- Inversely with the approach
- Inversely with the entering WBT

Heat Load

The **heat load 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.

The **size and cost of the cooling tower is proportional** to the heat load. If heat load calculations are low undersized equipment will be purchased. If the calculated load is high, oversize and more costly, equipment will result.

Wet bulb temperature

Theoretically, a cooling tower will cool water to the entering wet bulb temperature, when operating without a heat load. However, a thermal potential is required to reject heat, so it is not possible to cool water to the entering air wet bulb temperature, when a heat load is applied.

The approach obtained is a function of thermal conditions and tower capability.

The temperature selected is generally close to the average maximum wet bulb for the summer months

The Table illustrates the effect of approach on the size and cost of a cooling tower.

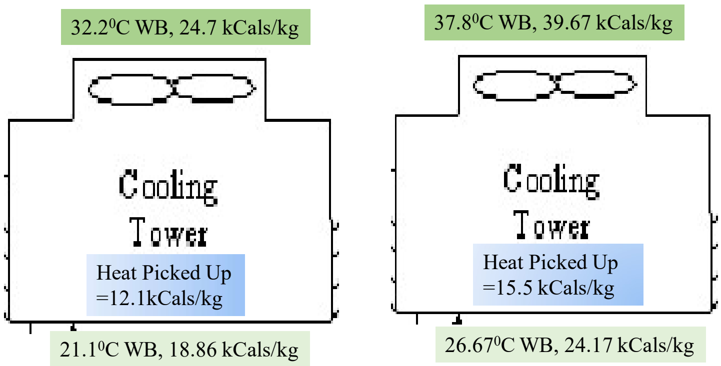
APPROACH Vs. COOLING TOWER SIZE (4540 m³/hr; 26.7°C Wet Bulb; 10.7 m Pump Head)						
Approach °C	2.77	3.33	3.88	4.44	5.0	5.55
Hot Water °C	46.11	46.66	47.22	47.77	48.3	48.88
Cold Water °C	29.44	30	30.55	31.11	31.66	32.22
No. of Cells	4	4	3	3	3	3
Length of Cells Mts.	10.98	8.54	10.98	9.76	8.54	8.54
Overall Length Mts.	43.9	34.15	32.93	29.27	25.61	25.61
No. of Fans	4	4	3	3	3	3
Fan Diameter Mts.	7.32	7.32	7.32	7.32	7.32	6.71
Total Fan kW	270	255	240	202.5	183.8	183.8

Approach & Wet Bulb Temperature

The design wet bulb temperature is determined by the geographical location and also a factor in cooling tower selection.Design wet bulb temperature selected is not exceeded over 5 % of the time in that area.

The **higher the wet bulb temperature**, the **smaller the tower required** to give a specified approach to the wet bulb at a constant range and flow rate

A 4540 m^3/hr cooling tower selected for a 16.67ºC range and a 4.45ºC approach to 21.11ºC wet bulb would be larger than a 4540 m^3/hr tower selected for a 16.67ºC range and a 4.45ºC approach to a 26.67ºC wet bulb. Air at the higher wet bulb temperature is capable of picking up more heat. Assume that the wet bulb temperature of the air is increased by approximately 11.1ºC.



FILLS

Function of Fill media in a Cooling Tower

Heat exchange between air and water is influenced by surface area of heat exchange, time of heat exchange (interaction) and turbulence in water effecting thoroughness of intermixing. **Fill media in a cooling tower is responsible to achieve all of above.**

Splash and Film Fill Media:.

Film Fill and its Advantages.

Film Fill and its Advantages

In a film fill, **water forms a thin film on either side of the fill sheets.** Thus area of heat exchange is the surface area

Table 7.3 Typical Comparisons Between Various Fill Media

	Splash Fill	Film Fill	Low Clog Film Fill
Possible L/G Ratio	1.1 – 1.5	1.5 – 2.0	1.4 – 1.8
Effective Heat Exchange Area	30 – 45 m^2/m^3	150 $m2/m^3$	85 – 100 m^2/m^3
Fill Height Required	5 – 10 m	1.2 – 1.5 m	1.5 – 1.8 m
Pumping Head Requirement	9 – 12 m	5 – 8 m	6 – 9 m
Quantity of Air Required	High	Much low	Low

Efficient System Operation

Cooling Water Treatment : Water Side Problems:

- **Corrosion and/or Scale formation**
- **Biological/Micro-biological fouling**
- **Systems exposed to sunlight** often meet with severe problem of algae formation. Other problems associated with algae are slime mass, fungi and various species of bacteria.

Solutions

- **ON line / OFF Line Chemical Cleaning-**
- **Side Stream Filter:**
- **Bio Dispersants and Biocides:**
- **Chlorination**

Drift Loss in the Cooling Towers

- drift loss requirement to as low as 0.003 – 0.001% change in drift eliminator shapes & efficient designs

Cooling Tower Fans

- An aerodynamic profile with optimum twist, taper can provide the fan total efficiency as high as 85–92 %.

Flow Control Strategies

1. **On-off Control of fans**
2. **Use of two- or three-speed fan motors**
3. **Use of automatically adjustable pitch fans**
4. **Use of variable speed fans.**

7.5 Energy Saving Opportunities in Cooling Towers

List ten energy saving measures

1. Replace old spray type nozzles with new square spray ABS non-clogging nozzles.
2. Replace splash bars with PVC cellular film fill.
3. Install new nozzles to get more uniform water pattern
4. Periodically clean nozzles.
5. Cover hot water basins to minimise algae growth-fouling.
6. Optimise blow down flow rate, as per COC limit.
7. Segregate high heat loads like furnaces, air compressors, DG sets, and isolate cooling towers for sensitive applications like A/C plants, condensers of captive power plant etc.
8. Consider energy efficient FRP blade adoption
9. CW pumps w.r.t. efficiency improvement.
10. Control cooling tower fans based on leaving water temperatures especially in case of small units.

Solved Example:

The energy audit observations at a cooling tower (CT) in a process industry are given below:

Cooling Water (CW) Flow: 3000 m^3/hr
CW in Temperature: 41deg. C
CW Out Temperature: 31 deg C
Wet Bulb Temperature: 24 deg. C

Find out Range, Approach, Effectiveness and cooling tower capacity in kcal per hour of the CT?

Ans:

Range = (Inlet -Outlet) Cooling Water Temperature deg. C

Range = (41 – 31) = 10 deg. C

Approach = (Outlet Cooling Water -Air Wet Bulb)Temperature deg. C
Approach = (31 – 24) = 7 deg C

% CT Effectiveness= Range / (Range + Approach) x 100
% Effectiveness = 100 x [Range / (Approach + Range)]
= 10 / [10+7] x 100 = 58.8 %

Cooling capacity, kcal/hr = heat rejected
= CW flow rate in kg per hour x (CW inlet hot water temp. to CT, deg. C - CW outlet cold well temp., deg. C)

Cooling capacity = 3000X1000X (41 - 31)
= 30,000,000 kCal per hour
= 30 Million kcal/hour.

QUESTIONS	
Objective Type Questions	
1.	The ratio of dissolved solids in circulating water to the dissolved solids in make up water is termed as _______. a) liquid gas ratio b) cycles of concentration c) cooling tower effectiveness d) none of the above
2.	If inlet and outlet water temperatures of a cooling tower are 40°C and 32°C respectively and atmospheric DBT and WBT are 35 °C and 28 °C respectively then the approach of cooling tower is a) 3°C b) 4°C c) 5°C d) 7°C
3.	Higher the COC in cooling tower , the blow down quantity will a) increases b) decreases c) no change d) none of the above
4.	The L/G ratio of a cooling tower does not depend on a) range b) enthalpy of inlet air c) outlet wet bulb temperature d) dry bulb temperature
5.	Which of the following ambient conditions will evaporate minimum amount of water in a cooling tower a) 35°C DBT and 30°C WBT b) 38°C DBT and 31°C WBT c) 38°C DBT and 37°C WBT d) 35°C DBT and 29°C WBT

Thank You

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