Heat Transfer: Heat Rejection

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COOLING TOWER

Cooling tower is a heat rejection device, which extracts waste heat to the atmosphere though the cooling of a water stream to a lower temperature.

Source : www.evwind.es

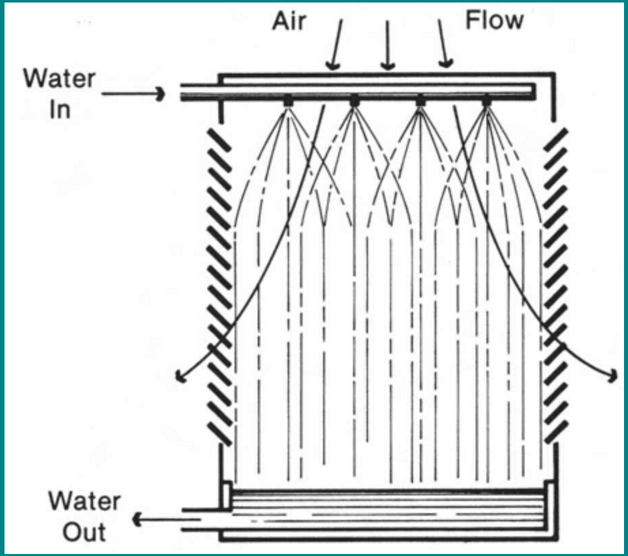
TYPES OF COOLING TOWER

Cooling towers are designed and manufactured in several types. Understanding the various types, along with their adventages and limitations, is important when determining the right tower for a project.

1. Atmospheric Towers
2. Mechanical Draft Towers
3. Hybrid Draft Towers
4. Characterization by Air Flow
5. Spray-fill Towers
6. Characterization by Construction
7. Characterization by Shape
8. Method of Heat Transfer

1. Atmospheric Towers

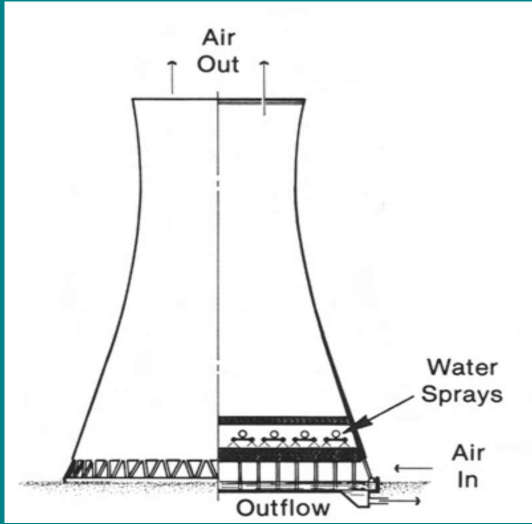
- Utilize no mechanical device (fan) to create air flow through the tower
- Usually applied only in very small sizes, and are far more affected by adverse wind conditions
- Although relatively inexpensive



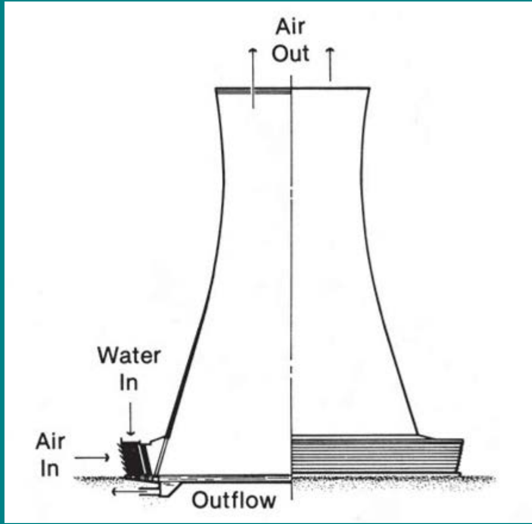
1. Atmospheric Towers

Hyperbolic Natural Draft

Air flow through this tower is produced by the density differential that exists between the heated (less dense) air inside the stack and the relatively cool (more dense) ambient air outside the tower



Counterflow natural draft tower



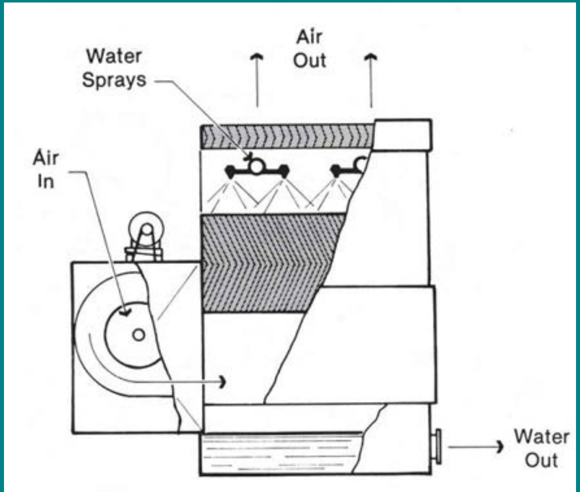
Crossflow natural draft tower

- Used extensively in the field of electric power generation
- Effectively in areas of higher relative humidity (not suitable for high altitude)

2. Mechanical Draft Towers

- Use either single or multiple fans to provide flow of air through the tower
- Thermal performance tends toward greater stability, affected by fewer psychrometric variables, than atmospheric towers

Forced Draft

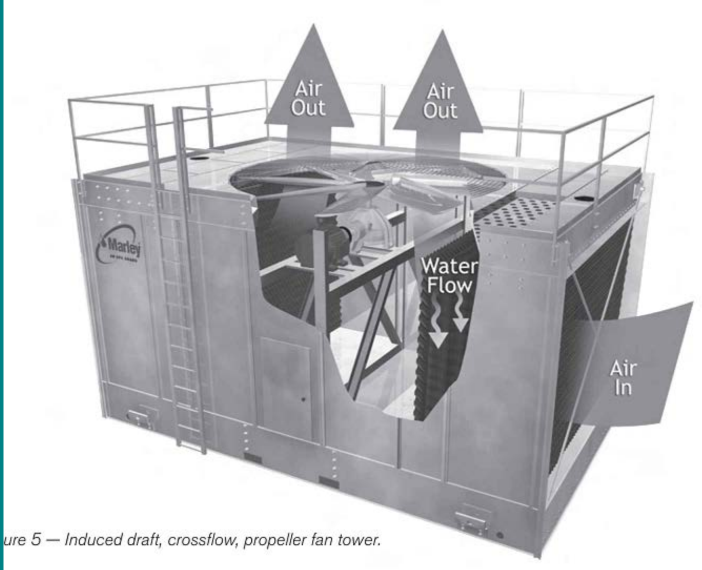


Forced draft, counterflow, blower fan tower

- High air entrance velocities and low exit velocities
- Usually equipped with centrifugal blower fans, although requiring more power than propeller fans, have the adventages to operate against the high static pressures associated with ductwork.

2. Mechanical Draft Towers

Induced Draft



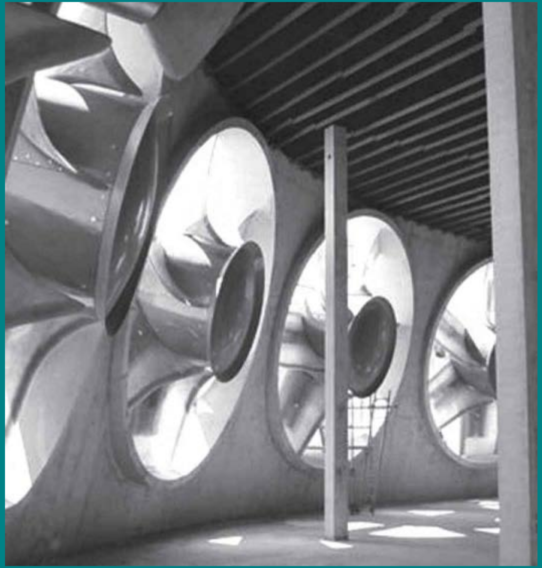
Induced draft, crossflow, propeller fan tower

- Have an air discharge velocity 3-4 times higher than entrance velocity
- Location of the fan within the warm air steam provides excellent protection against the formation of ice on the components

3. Hybrid Draft Towers

- Give the outward appearance of natural draft tower with relative short stacks
- Equipped with mechanical draft fans to augment air flow.
- The intent of the design is to minimize the power required for air movement, but to do so with the least possible stack cost impact.

Fan-assisted natural draft tower

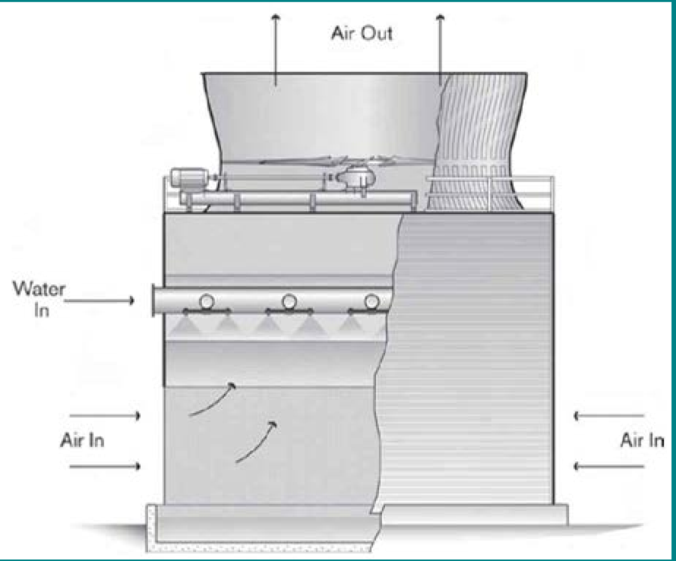


Inside of a Fan-assisted natural draft tower

4. Characterization by Air Flow

Cooling towers are also "typed“ by the relative flow relationship of air and water within the tower.

Counterflow Towers



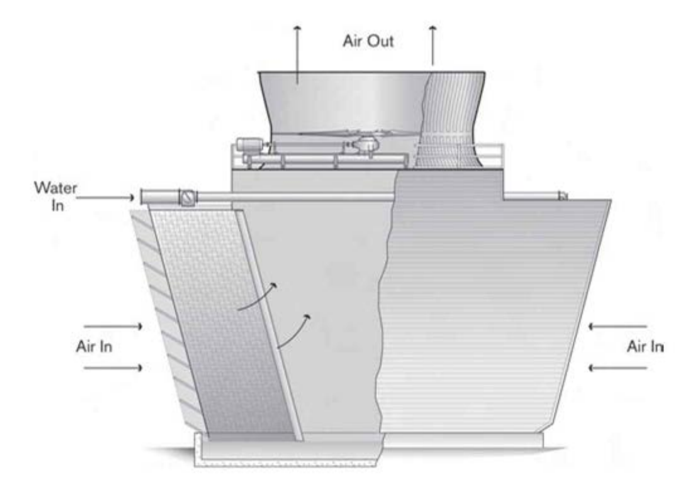
Induced draft counterflow tower

- Air moves vertically upward through the fill, counter to the downward fall of water.
- Use high-pressure spray systems
- Typically higher air pressure losses
- Require more pump head
- Utilize more fan power than crossflow

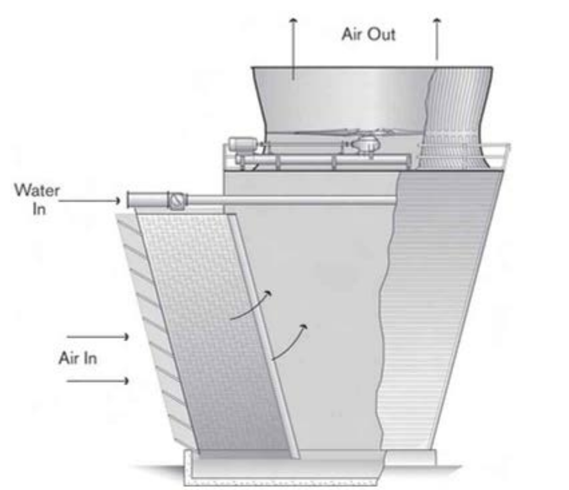
4. Characterization by Air Flow

Crossflow Towers

- The air flows horizontally, across the downward fall of water.
- Water to be cooled is delivered to hot inlet basins located atop the fill areas.
- Single flow is used in locations where an air path to the tower is available from one direction.



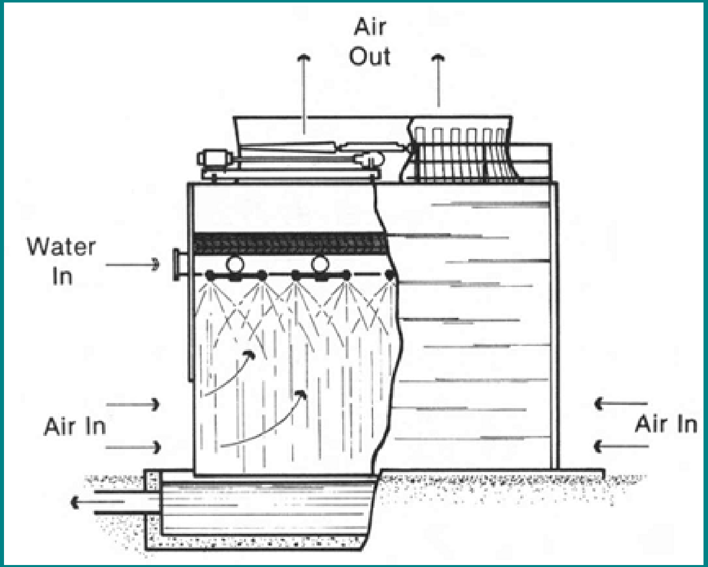
Induced draft, double-flow, crossflow tower



Induced draft, single-flow, crossflow tower

5. Spray-fill Towers

- Have no heat transfer (fill) surface, depending only upon the water break-up afforded by distribution system to promote maximum water-to-air contact
- Utilized in the situations where excessive contaminants or solids in circulating water would jeopardize a normal heat transfer surface



Spray-fill, counter flow cooling tower

6. Characterization by Construction

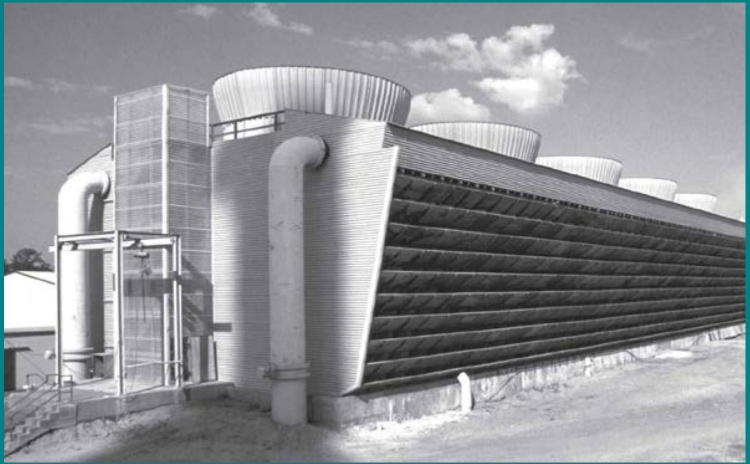
- Field-erected Towers are on which the primary construction activity takes place at the site of ultimate use. All large towers are prefabricated, piece-marked, and shipped to the site for the final assembly.

Small factory-assembled tower

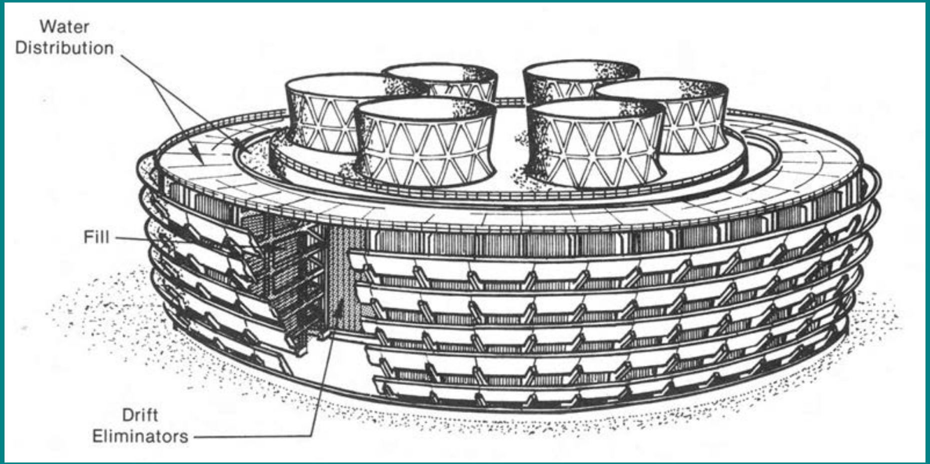
- Factory-assembled Towers undergo virtually complete assembly at their point of manufacture, whereupon they are shipped to the site as few sections as the mode of transportation will permit

7. Characterization by Shape

- Rectilinear Towers are constructed in cellular fashion, increasing linearly to the length and number of cells to accomplish specified thermal performance
- Round Mechanical Draft (RMD) Towers are essentially round in plan configuration, with fans clustered as close as practicable around the centerpoint of the tower. This type can handle enormous heat loads with less site area impact



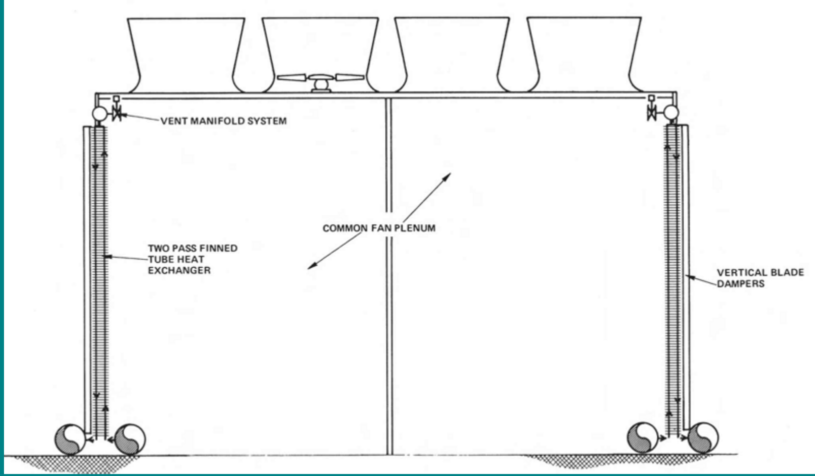
Multi-cell, field-erected, crosslow cooling tower



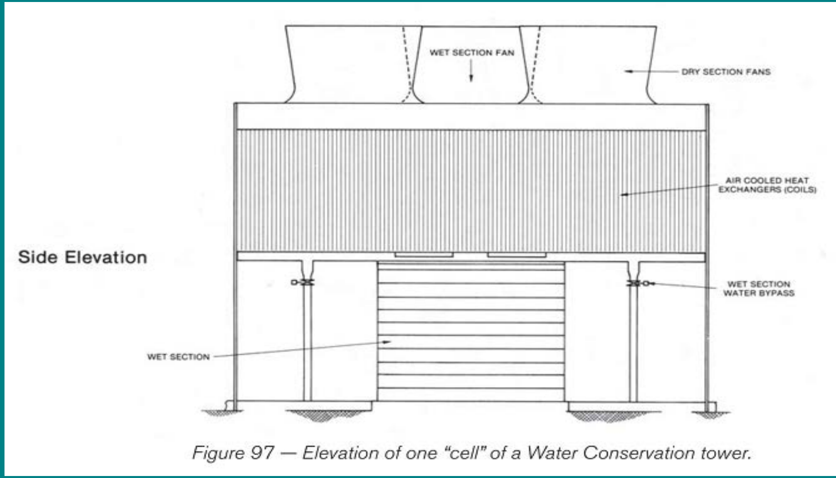
Round mechanical draft, crossflow tower

8. Method of Heat Transfer

- Dry Towers: utilization of dry surface coil sections, no direct contact (no evaporation) occurs between air and water. So the water is cooled totally by sensible heat transfer
- Plume Abatement and Water Conservation Towers: progressively greater portions of dry surface coil sections are introduced into the overall heat transfer system to accomplish specific requirements.



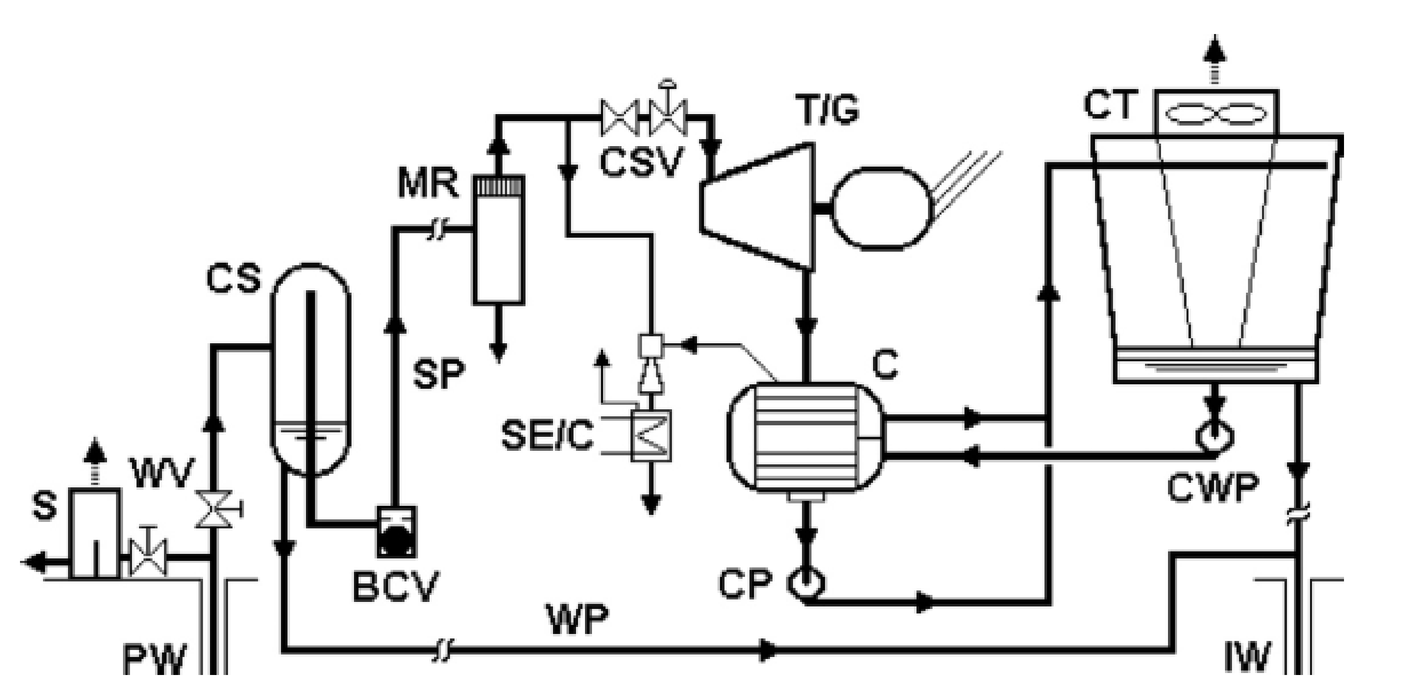
Cross-section elevation of dry tower



Water conservation towers

Cooling Tower Analysis

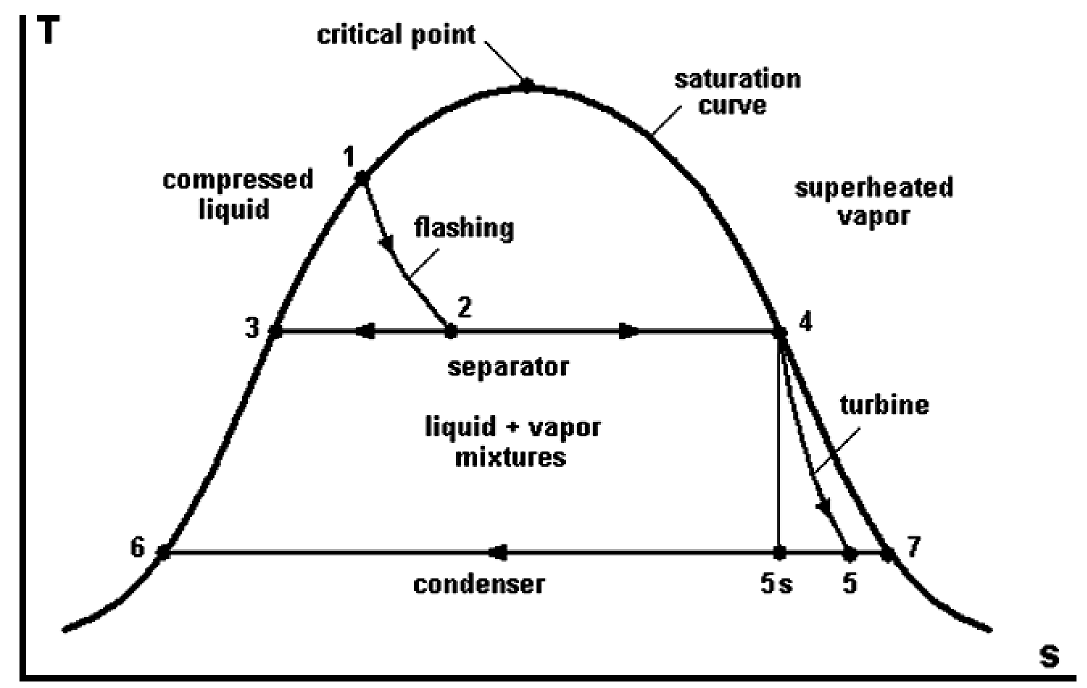
Simplified single-flash power plant schematic



DiPippo, Ronald, Geothermal power plants : principles, applications, case studies, and environmental impact. 3rd ed, 2012

Cooling Tower Analysis

Temperature-entropy state diagram for single-flash plants



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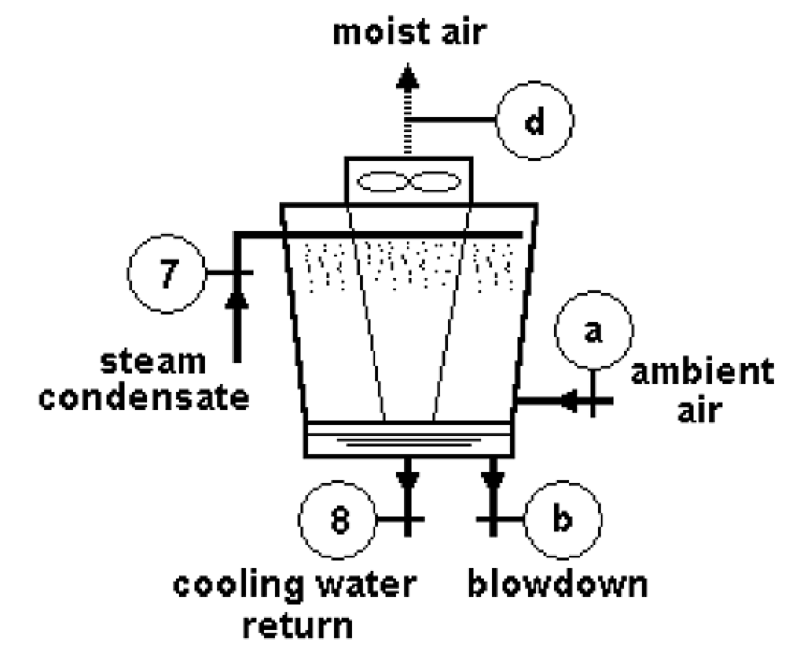
Cooling Tower Analysis

Cooling tower schematic of mechanical induced-draft cooling tower



The steam condensate that has been pumped from the condenser hotwell is sprayed into the tower where it falls through an air stream drawn into the tower by a motor-driven fan at the top of the tower. The ambient air enters with a certain amount of water vapor, determined by its relative humidity, and picks up more water vapor as the condensate partially evaporates

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Cooling Tower Analysis

The internal process involves the exchange of both heat and mass between the air and the water. The following First Law equation describes the overall operation of the tower, excluding the fan and assuming steady flow and overall adiabatic conditions:

$$\dot{m}_7 h_7 - \dot{m}_8 h_8 = \dot{m}_d h_d - \dot{m}_a h_a + \dot{m}_b h_b$$

Mass conservation of water : $\dot{m}_7 + \dot{m}_{wa} = \dot{m}_8 + \dot{m}_b + \dot{m}_{wd}$

Mass conservation of air : $\dot{m}_{ad} = \dot{m}_{aa}$

$\dot{m}_{wa}$ and $\dot{m}_{wd}$ represent the water content of the incoming and leaving air streams. These can be found from the specific humidity, ω, of the air streams:

$$\dot{m}_{wa} = \omega_a \dot{m}_a$$

$$\dot{m}_{wa} = \omega_d \dot{m}_d$$

These governing equations are used with the properties of steam, water and moist air, either in tabular, graphic (psychrometric chart), or electronic form to determine the various flow rates needed for given design conditions.

Cooling Tower Analysis

Cooling towers for geothermal power plants are much larger in cooling capacity than for conventional fossil or nuclear power plants of the same power rating. The net heat added to the cycle must equal the net work delivered by the cycle, or in terms of thermal and mechanical power.

$$\dot{Q}_{in} - \dot{Q}_o = \dot{W}_e$$

So, the thermal efficiency of the plant is:

$$\eta_{th} = \frac{\dot{W}_e}{\dot{Q}_{in}}$$

Cooling Tower Problems

Typical problems and trouble shooting for cooling towers

Problem / Difficulty	Possible Causes	Remedies/Rectifying Action
Excessive absorbed current / electrical load	1. Voltage Reduction	Check the voltage
	2a. Incorrect angle of axial fan blades	Adjust the blade angle
	2b. Loose belts on centrifugal fans (or speed reducers)	Check belt tightness
	3. Overloading owing to excessive air flow-fill has minimum water loading per m^2 of tower section	Regulate the water flow by means of the valve
	4. Low ambient air temperature	The motor is cooled proportionately and hence delivers more than name plate power
Drift/carry-over of water outside the unit	1. Uneven operation of spray nozzles	Adjust the nozzle orientation and eliminate any dirt
	2. Blockage of the fill pack	Eliminate any dirt in the top of the fill
	3. Defective or displaced droplet eliminators	Replace or realign the eliminators
	4. Excessive circulating water flow (possibly owing to too high pumping head)	Adjust the water flow-rate by means of the regulating valves. Check for absence of damage to the fill

Cooling Tower Problems

Typical problems and trouble shooting for cooling towers

Problem / Difficulty	Possible Causes	Remedies/Rectifying Action
Loss of water from basins/pans	1. Float-valve not at correct level	Adjust the make-up valve
	2. Lack of equalising connections	Equalise the basins of towers operating in parallel
Lack of cooling and hence increase in temperatures owing to increased temperature range	1. Water flow below the design valve	Regulated the flow by means of the valves
	2. Irregular airflow or lack of air	Check the direction of rotation of the fans and/or belt tension (broken belt possible)
	3a. Recycling of humid discharge air	Check the air descent velocity
	3b. Intake of hot air from other sources	Install deflectors
	4a. Blocked spray nozzles (or even blocked spray tubes)	Clean the nozzles and/or the tubes
	4b. Scaling of joints	Wash or replace the item
	5. Scaling of the fill pack	Clean or replace the material (washing with inhibited aqueous sulphuric acid is possible but long, complex and expensive)