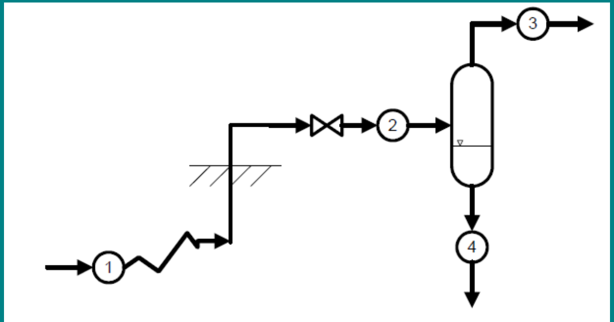
Introduction to Geothermal Power Plant Components (2)

Prepared by: Geocap Team & PPSDM EBTKE

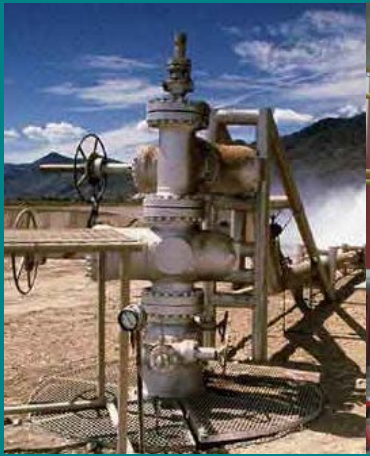
Presented by: Khasani

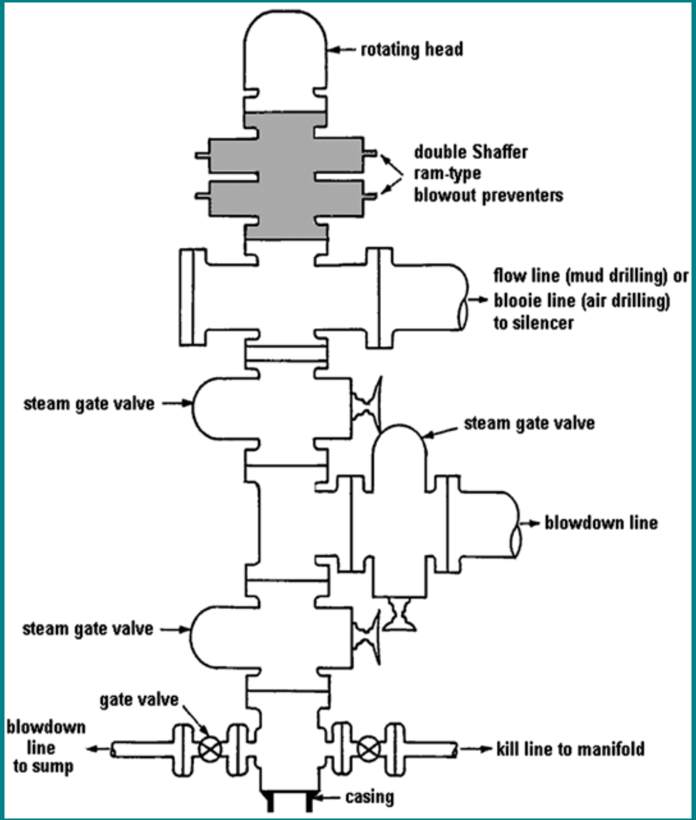
Training for Engineers on
Geothermal Power Plant
Yogyakarta, 9-13 October 2017

Wellhead



Simple model of wellhead and separator



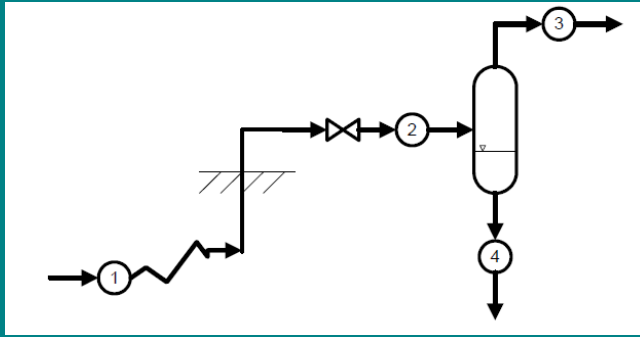


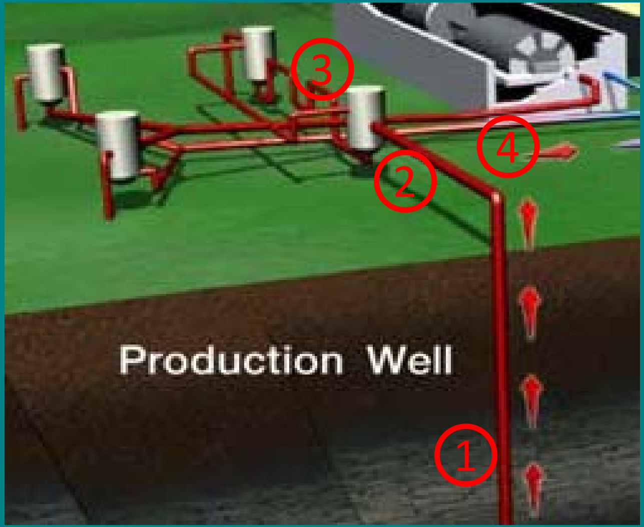
Separator

- Two-phase fluid flows from geothermal wells to the separator. One separator can serve one or more geothermal wells.
- Because it would be difficult to transport the fluid to the above level, the separator is usually placed in the lower elevations of the wells with piping downwards.
- It becomes challenge if the topographical conditions of geothermal fields are mountainous and hilly.
- The fluid flows in pipes may reach the speeds of about 70-90 km/ h with water flowing at the bottom of the pipe.

- Point 1 represents the undisturbed geothermal reservoir. Point 2 is the entry of the steam-water separator, point 3 is the steam outlet from the separator and station 4 is the brine outlet of the separator.
- The wells have certain productivity, i.e. there is a relation between the wellhead pressure and the flow from the well.

$$\dot{□}_Q \; Â \; □H□_R I$$





- The flow up the well and in the geothermal primary system can usually be treated as isenthalpic, means that the heat loss in the well and the piping is neglected.

$$\dot{m}_2 = \dot{m}_1 \qquad h_2 = h_1$$

- The throttling in the well and primary system results most frequently in that the fluid starts to boil, which results in that the temperature is a direct function of the separator pressure (Point 2). If boiling occurs and a separator is employed,

$$T_2 = T_{sat}(P_2)$$

- The mass flow of steam from the separator will thus be:

$$\dot{\square}_S \ \text{Â} \ \dot{\square}_R \frac{\square_R \ \text{ù} \ \square_T}{\square_S \ \text{ù} \ \square_T}$$

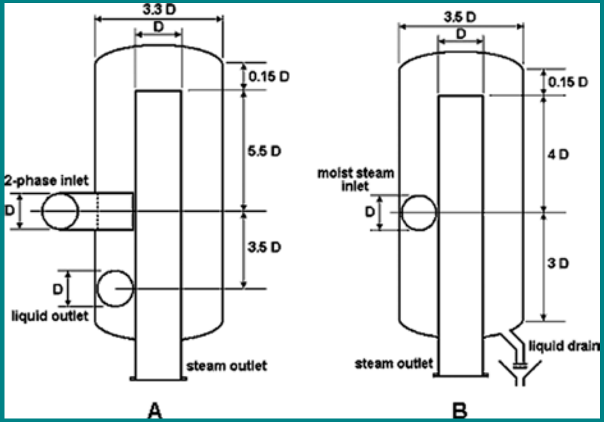
- All temperatures in the separator will thus be equal, assuming that there are no significant pressure losses or pressure differences within the separator.

$$\square_S \ \text{Â} \ \square_R \ \text{Â} \ \square_T \ \text{Â} \ \square_{\square\square\square}\text{H}\square_R\text{I}$$

- The enthalpy of the steam outgoing stream from the separator is thus the enthalpy of saturated steam at the separator pressure

$$\dot{\square}_T \ \text{Â} \ \dot{\square}_R \ \text{ù} \ \dot{\square}_S$$

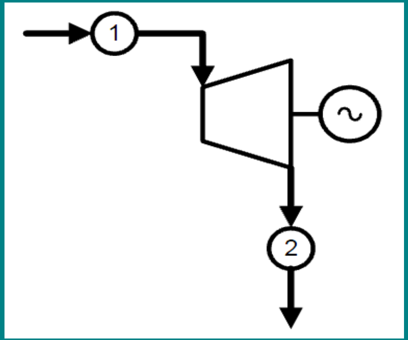
- The selection of the separator pressure is thus an optimization process, economical, thermodynamic and geothermal fluid.
- The designs were based on a combination of theory and empirical correlations.



General design specifications for cyclone separator (A) and cyclone moisture remover (B)

Parameter	Separator	Moisture remover
Maximum steam velocity at the 2-phase inlet pipe	45 m/s	60 m/s
Recommended range of steam velocity at the 2-phase inlet pipe	25–40 m/s	35–50 m/s
Maximum upward annular steam velocity inside cyclone	4.5 m/s	6.0 m/s
Recommended range of upward annular steam velocity inside cyclone	2.5–4.0 m/s	1.2–4.0 m/s

Turbine

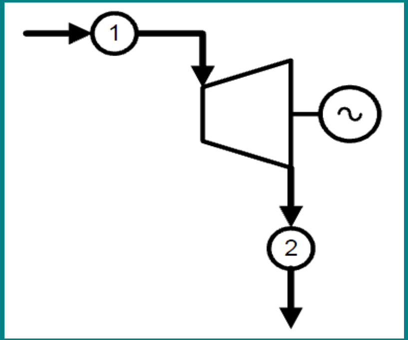


A schematic diagram of turbine

- Turbine converts the enthalpy of steam into the work then generates electricity in a generator.
- Basically, a geothermal turbine is similar to a general steam turbine with many modifications to adjust the conditions of geothermal field. Two common types are single and dual flash turbines. The second type is able to generate power slightly greater for liquid dominated reservoirs.

- However, there are challenges to this case due to the presence of the low-pressure in part of turbine that is usually deposited by silica.

- Point 1 is the vapour inlet to the turbine, and station 2 is the turbine exit.
- The ideal turbine is isentropic, having no second law losses. In this case the entropy of the incoming vapor equals the entropy in the exhaust steam.
- The corresponding enthalpy change (reduction) of the vapor is the largest enthalpy change possible.
- The isentropic exit enthalpy is then the enthalpy at the same entropy as in the inlet and at the exit pressure,



□R□ Â □H□QL □RI

- The turbine isentropic efficiency is given by the turbine manufacturer.
- This efficiency is the ratio between the real enthalpy change through the turbine to the largest possible (isentropic) enthalpy change.
- The real turbine exit enthalpy can then be calculated

$$h_2 = h_1 - \eta_{t}(h_1 - h_{2s})$$

- The work output of the turbine is then the real enthalpy change multiplied by the working fluid mass flow through the turbine.

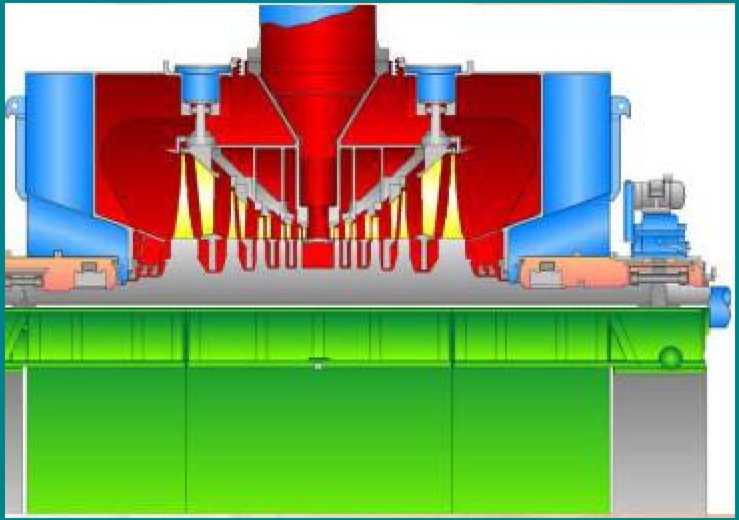
$$\dot{W} = \dot{m}(h_1 - h_2)$$

- The turbines used in geothermal applications must be made of corrosion-resistant materials owing to the presence of gases such as hydrogen sulfide that can attack ordinary steel.
- Various alloys have been successfully used for turbine steam-path elements, e.g., nozzles, blades, diaphragms, etc.
- Typical geothermal turbine inlet steam conditions are saturated with pressures that range from 5–10 bar.
- As a result, significant amounts of moisture appear in the steam path of geothermal turbines, particularly in the lowest pressure stages.

Turbine Design

Single or Double flow in single casing designs

- Multiple casings for multiple exhaust flows to reduce exhaust losses
- Need to be very robust machines for the steam conditions
- Dissolved gases in condensate are corrosive– stress corrosion cracking
- Entrained particles are erosive to inlet valves, nozzle sand blades
- High quality rotor forgings to limit impurities and reduce likelihood of SCC

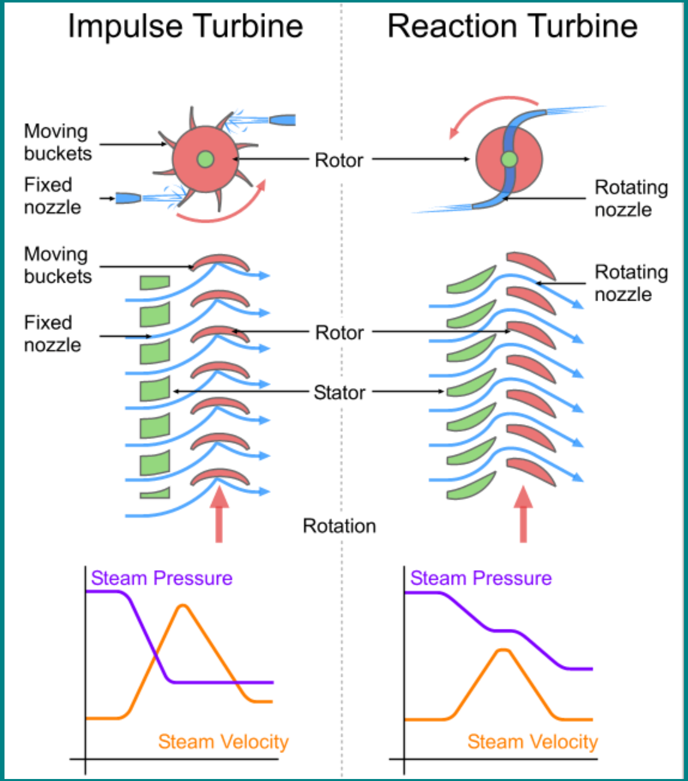


Steam Turbine Blades

- Steam turbine blades are subjected to high thermal stresses
- Made of Ni-chrome steel
- Geothermal fluid may contain solids (sand, silica)

Impulse & Reaction Turbines

- An **impulse turbine** has fixed nozzles that orient the steam flow into high speed jets.
- These jets contain significant kinetic energy, which the rotor blades, shaped like buckets, convert into shaft rotation as the steam jet changes direction.
- A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage.



- In the **reaction turbine**, the rotor blades themselves are arranged to form convergent nozzles.
- This type of turbine also makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor.
- Steam is directed on to the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor.
- The steam then changes direction and increases its speed relative to the speed of the blades.
- A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

Principal Parts of Turbine

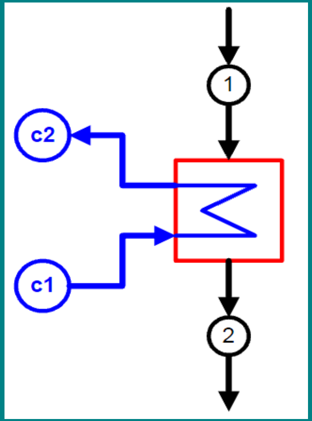
1. Rotor: Main moving element of turbine
2. Casing: Stationary element, often called the cylinder. It surrounds the rotor and holds internally any nozzles, blades and diaphragms that may necessary to control the physical state of expanding steam.
3. Bearings

   There are two types of bearings: a) Journal bearings (Front journal bearing Rear journal bearing), b) Thrust bearing
4. Shaft seals: A Point where shaft emerges from the casing it needs sealing to prevent steam outflow at high pressure end and air inflow at the vacuum end.

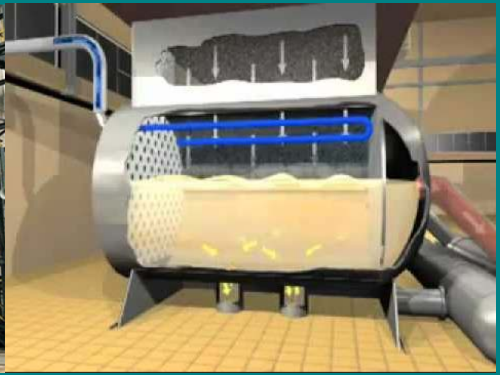
In large turbine where shaft diameter is large Labyrinth glands with steam leak off at high pressure end and steam and water sealing at condenser end are provided.

5. Governing System: To maintain speed of turbine constant irrespective of load on turbine.
6. Oil system: Main function of oil system is to provide lubrication to bearings of turbine, also oil pressure as a part of hydraulic system to governing system.

Condenser



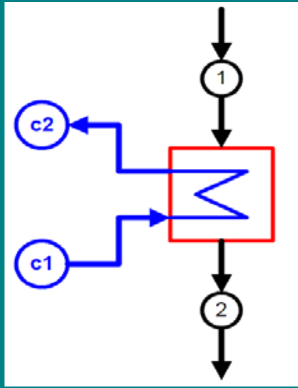
- The condenser is used to condense the steam coming from the turbine.
- Steam from the turbine enters from the top side of the condenser, then condensed as a result of the absorption of heat by the cooling fluid injected into the condenser.
- The cooling fluid can be the water or air.



- The steam from the turbine is condensed by means of either a surface-type condenser, or in a direct-contact condenser of either the barometric or low-level type.

- Most plants now employ surface condensers in which the geothermal steam passes through the shell side and cooling water passes through the tube side.
- This maintains physical and chemical separation between the geothermal steam and the cooling water, and allows more effective removal and treatment of non-condensable gases.
- Gases such as carbon dioxide and hydrogen sulfide exist with the natural steam and do not condense at the temperatures in the condenser.
- Therefore unless they are removed they will increase the overall pressure in the condenser and lower the turbine power output.
- Steam jet ejectors with after-condensers, and/or vacuum pumps are used for this purpose.

- Point 1 is the working fluid coming from the turbine.
- Point 2 is the condensed fluid, normally saturated liquid with little or no sub-cooling.
- Point c1 is the entry of the cooling fluid, station c2 the outlet.



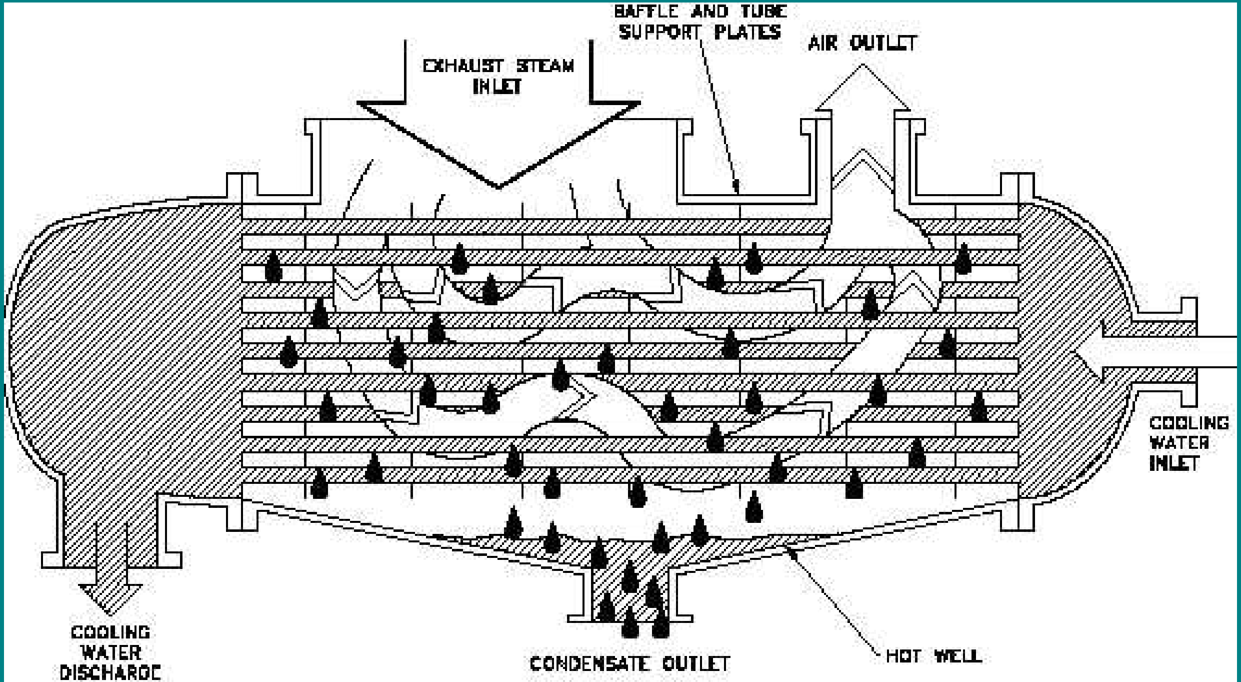
- The condenser is nothing but a heat exchanger between the hot vapor from the turbine and the cooling working fluid of the cycle.
- It has to be observed that the temperature of the hot fluid is higher than the one of the cold fluid throughout the condenser.

- The required flow rate of cooling water, $\dot{m}_{cw}$, to the steam flow rate, $x\dot{m}_{total}$:

$$\dot{m}_{cw} = x\dot{m}_{total}\left[\frac{h_4 - h_5}{\bar{c}\,\Delta T}\right]$$

- Where *x* is the steam fraction in the separator, $\bar{c}$ is the assumed constant specific heat of the cooling water (4.2 kJ/kg.K) and Δ*T* is the rise in cooling water temperature as it passes through the condenser.

Steam Condenser Design



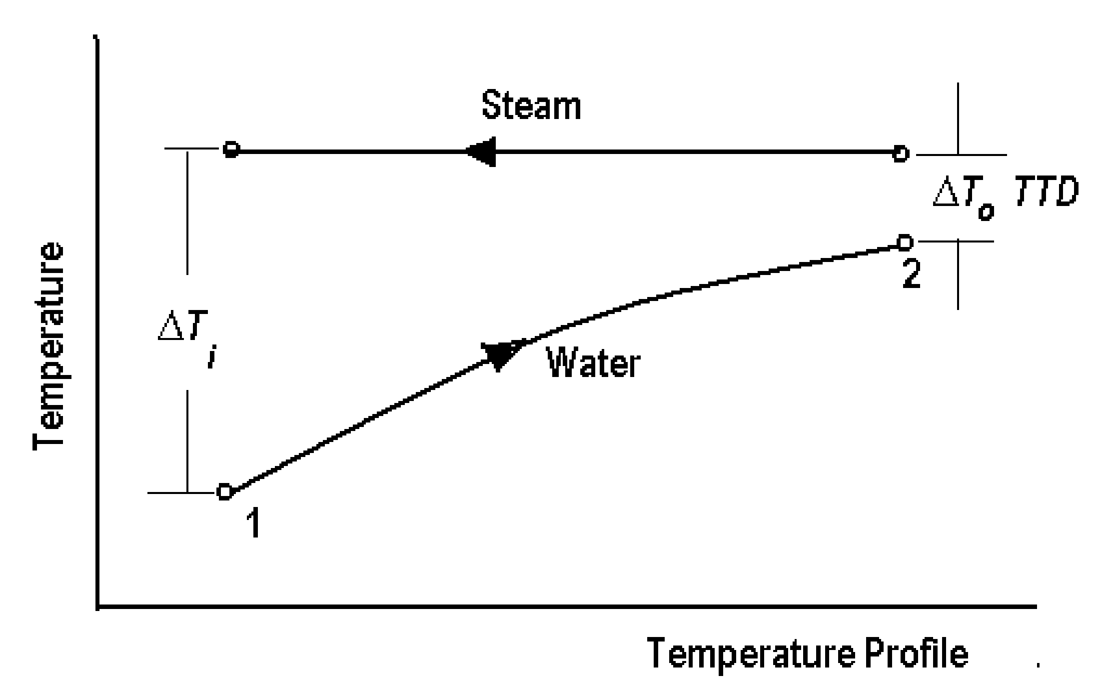
Assumption while design heat exchanger

1. The heat exchanger operates under steady-state conditions [i.e., constant flow rates and fluid temperatures (at the inlet and within the exchanger) independent of time].
2. Heat losses to or from the surroundings are negligible (i.e. the heat exchanger outside walls are adiabatic).
3. There are no thermal energy sources or sinks in the exchanger walls or fluids, such as electric heating, chemical reaction, or nuclear processes.
4. The temperature of each fluid is uniform over every cross section in counter flow and parallel flow exchangers. For a multi pass exchanger, the foregoing statements apply to each pass depending on the basic flow arrangement of the passes; the fluid is considered mixed or unmixed between passes as specified.

5. Wall thermal resistance is distributed uniformly in the entire exchanger.
6. The phase change occurs at a constant temperature as for a single-component fluid at constant pressure; the effective specific heat cp_{eff} for *the* phase-changing fluid is infinity in this case, and hence $C_{max} = mcp_{eff}$, where *m* is the fluid mass flow rate.
7. Longitudinal heat conduction in the fluids and in the wall is negligible.
8. The individual and overall heat transfer coefficients are constant(independent of temperature, time, and position) through out the exchanger, including the case of phase changing fluids in assumption 6.
9. The specific heat of each fluid is constant through out the exchanger, so that heat capacity rate on each side is treated as constant.

10. The heat transfer surface area *A is distributed uniformly on each fluid side in a* single-pass or multi pass exchanger. In a multi pass unit, the heat transfer surface area is distributed uniformly in each pass, although different passes can have different surface areas.
11. The velocity and temperature at the entrance of the heat exchanger on each fluids side are *uniform over the flow cross section. There is no gross flow misdistribution at the* inlet.
12. The fluid flow rate is uniformly distributed through the exchanger on each fluid side in each pass i.e., no passage-to-passage or viscosity-induced misdistribution occurs in the exchanger core. Also, no flow stratification, f low by passing, or flow leakages occur in any stream. The flow condition is characterized by the bulk (or mean) velocity at any cross section

Heat Transfer Process



Condenser Types

JET CONDENSERS

The exhaust steam and cooling water come indirect contact and as a result the steam is condensed. It is also called ***direct contact condensers.***

SURFACE CONDENSERS

The cooling water flows through a net work of tubes and the exhaust steam passes over these tubes. The steam gets condensed due to heat transfer to coolant by conduction and convection.

Condenser Comparison

No	Jet condensers	Surface condensers
1.	Steam and water comes in direct contact.	Steam and water does not come in direct contact.
2.	Condensation is due to mixing of coolant.	Condensation is due to heat transfer by conduction and convection.
3.	Condensate is not fit for use as boiler feed until the treated cooling water is supplied.	Condensate is fit for reuse as boiler feed.
4.	It is cheap. Does not affect plant efficiency.	It is costly. Improves the plant efficiency.
5.	Maintenance cost is low.	Maintenance cost is high.
6.	Vacuum created is up to 600 mm of Hg.	Vacuum created is up to 730 mm of Hg.

Surface Condenser

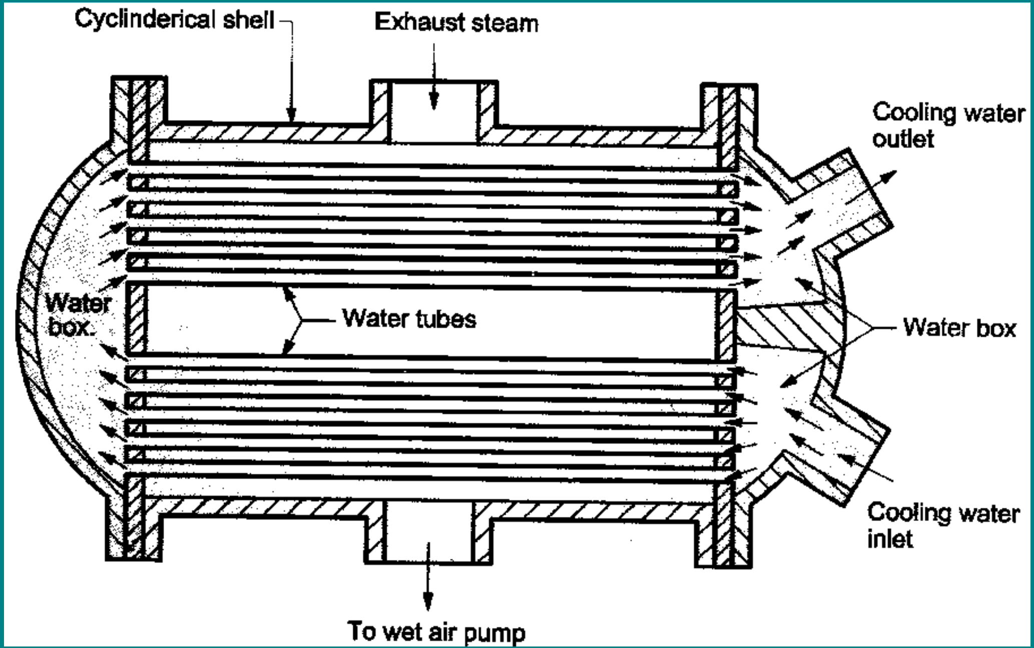
SURFACE CONDENSERS

In this steam flows out side the net work of tubes and water flows inside the tubes.

EVAPORATIVE CONDENSERS

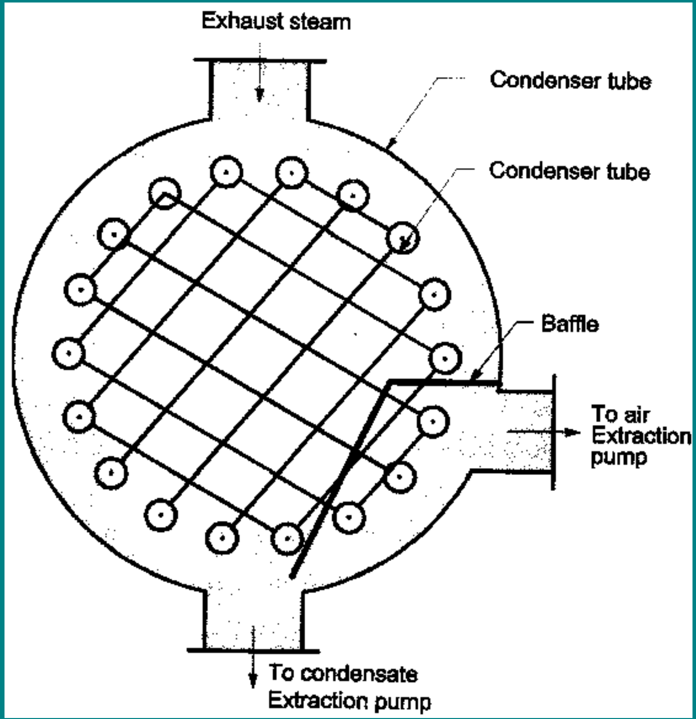
In this condenser shell is omitted. The steam passes through condenser tubes, the water is sprayed while the air passes upward outside the tube.

Double Pass Surface Condenser



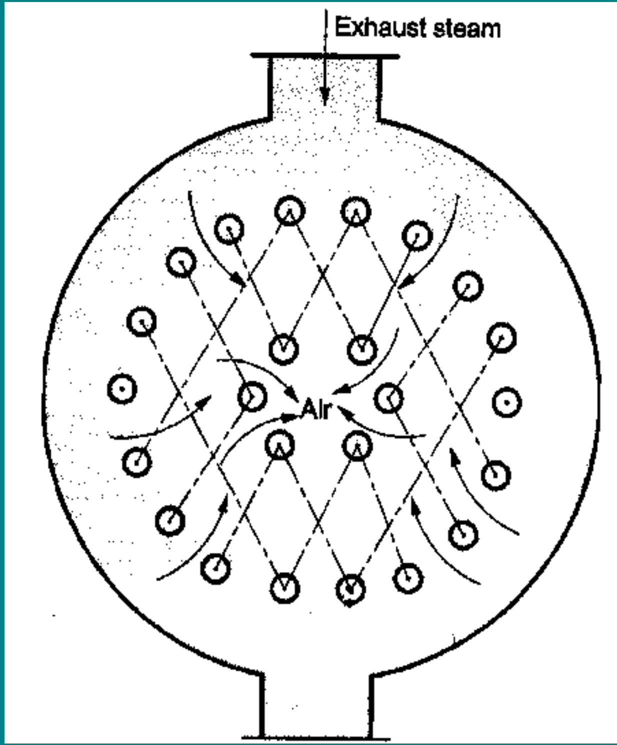
- It consists of air tight cast iron cylindrical shell.
- If cooling water is impure, condenser tubes are made up of red brass.

Down Flow Surface Condenser



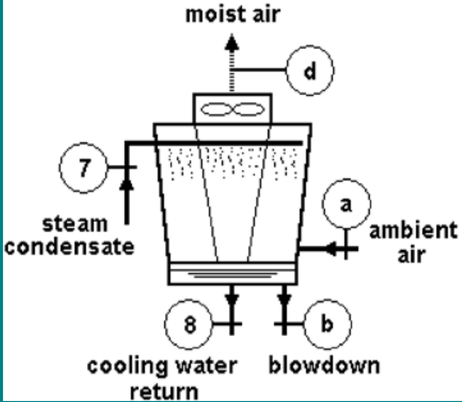
- This condenser employs two separate pumps for the extraction of condensate and the air.
- Baffles are provided so that the air is cooled to the minimum temperature before it is extracted.
- The specific volume of cooled air reduces, thereby, reduces the pump capacity to about 50%. Therefore, it also reduces the energy consumption for running the air pump.

Central Flow Surface Condenser

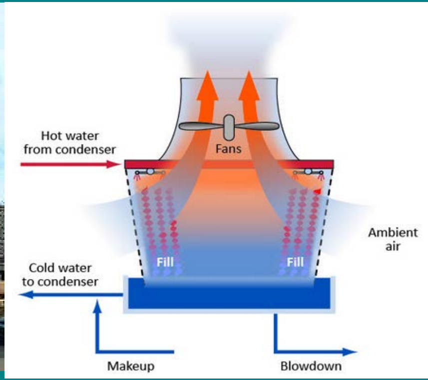


- Air extraction pump is located at the center of the condenser tubes.
- Condensate is extracted from the bottom of the condenser with the help of condensate extraction pump.
- Provides the better contact of steam.

Cooling Tower



- The condensate from the turbine and condenser of dry or wet steam power plants is usually used in the cooling system.
- This type of system is cheaper to build and operate when the water needed for cooling is available and not expensive.
- This system may lose the water primarily due to evaporation of the water.

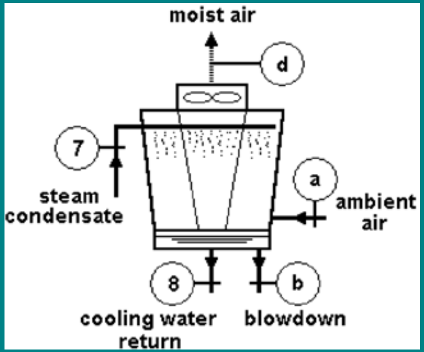


- Emission from this type of cooling type (water vapor with a solid / dissolved minerals) is strongly influenced by the quality of the geothermal fluid that is injected back into the geothermal power plant system.

- The cooling tower must be designed to accommodate the heat load from the condensing steam.
- The steam condensate that has been pumped from the condenser hot-well 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.
- The evaporation process requires heat that comes from the water itself, thereby dropping its temperature.

- The following First Law equation describes the overall operation of the tower, excluding the fan and assuming steady flow and overall adiabatic conditions:

$$\dot{\square}_Q \square_Q \ \text{ù} \ \dot{\square}_R \square_R \ \hat{A} \ \dot{\square}_\square \square_\square \ \text{ù} \ \dot{\square}_\square \square_\square \ K \ \dot{\square}_\square \square_\square$$



- The conservation equations:

$$\dot{\square}_Q \ K \ \dot{\square}_{\square\square} \ \hat{A} \ \dot{\square}_R \ K \ \dot{\square}_\square \ K \ \dot{\square}_{\square\square} \qquad \text{(Conservation of water)}$$

$$\dot{\square}_{\square\square} \ \hat{A} \ \dot{\square}_{\square\square} \qquad \text{(Conservation of dry air)}$$

- Where the terms $\dot{\square}_{\square\square}$ and $\dot{\square}_{\square\square}$ represent the water content of the incoming and leaving air streams, respectively with the specific humidity, ω, of the air streams:

$$\dot{\square}_{\square\square} \ \hat{A} \ \square_\square \dot{\square}_\square \qquad \dot{\square}_{\square\square} \ \hat{A} \ \square_\square \dot{\square}_\square$$

Cooling Tower Design

Wet Cooling Tower

- Uses evaporation to transfer heat
- Water can be cooled to a temperature lower than the ambient air “dry-bulb” temperature.

Dry Cooling Tower

- Uses convection to transfer heat
- Heat is transferred through a surface that separates the water from ambient air, such as in a heat exchanger.

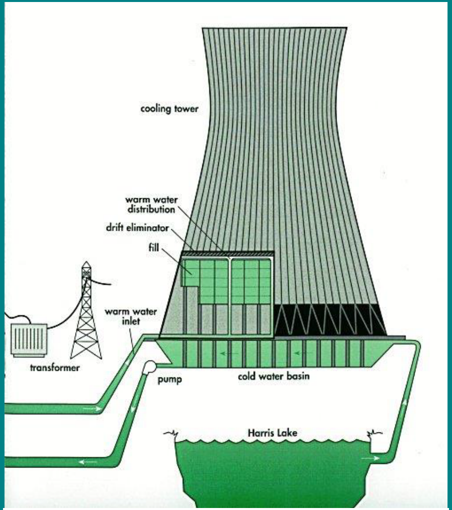
Air Flow Generation Methods

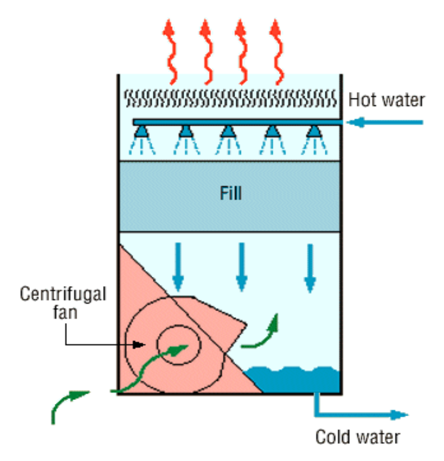
Natural Draft

Warm air naturally rises due to the density differential to the dry, cooler outside air. This moist air buoyancy produces an airflow through the tower.

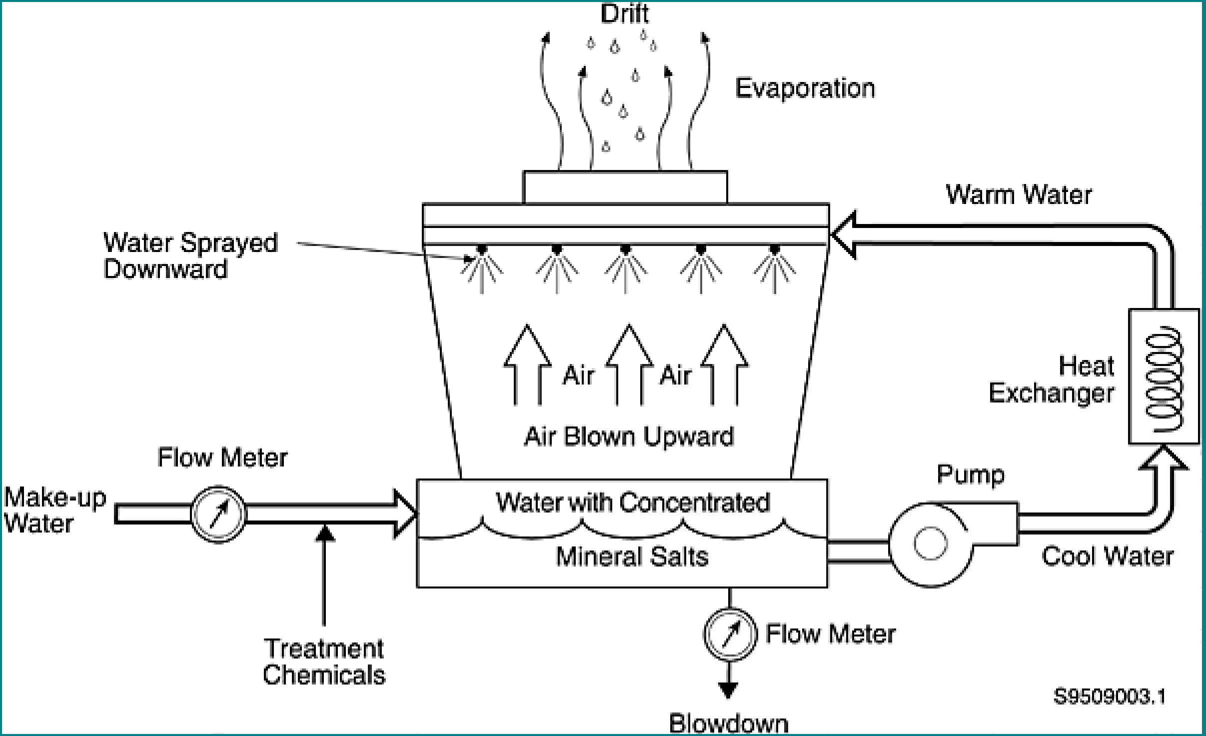
Mechanical Draft

A fan induces airflow through a tower.





Main Features of Cooling Towers



COMPONENTS OF COOLING TOWER

- Frame and casing: support exterior enclosures
- Fill: facilitate heat transfer by maximizing water/air contact
  - Splash fill
  - Film fill
- Cold water basin: receives water at bottom of tower

COMPONENTS OF COOLING TOWER

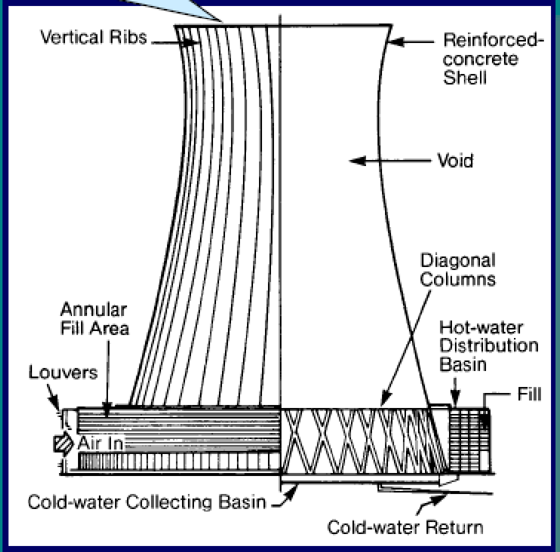
- Drift eliminators: capture droplets in air stream
- Air inlet: entry point of air
- Louvers: equalize air flow in to the fill and retain water with in tower
- Nozzles: spray water to wet the fill
- Fans: deliver air flow in the tower

Natural Draft Cooling Towers

- Hot air moves through tower
- Fresh cool air is drawn into the tower from bottom
- No fan required
- Concrete tower<200m
- Used for large heat duties

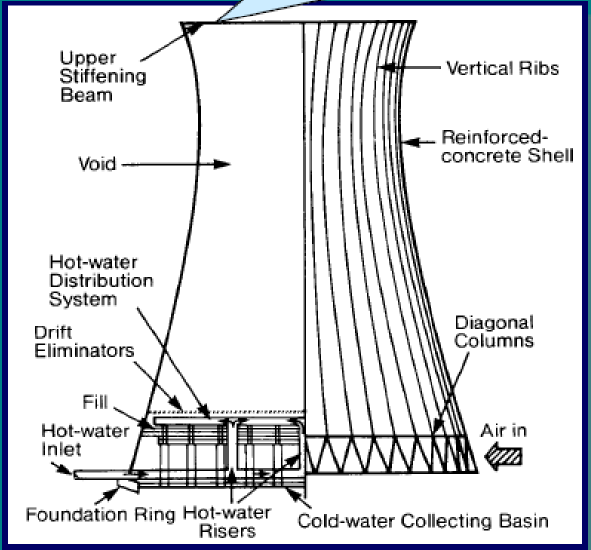
Natural Draft Cooling Towers

- Air drawn across falling water
- Fill located outside tower



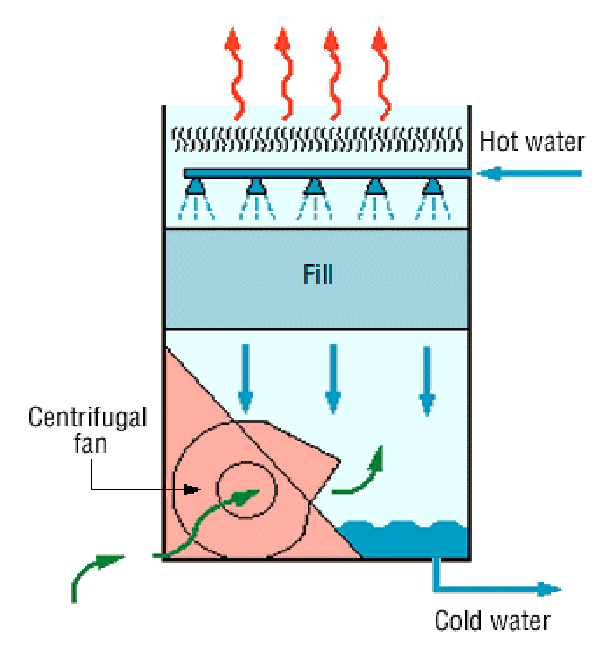
Cross flow

- Air drawn up through falling water
- Fill located inside tower



Counter flow

Forced Draft Cooling Towers



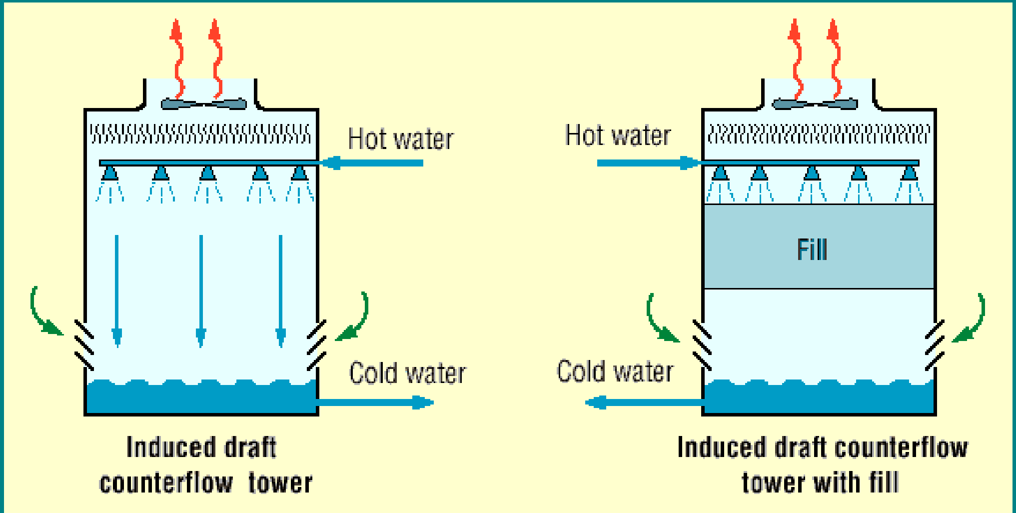
- Air blown through tower by centrifugal fan at air inlet
- Advantages: suited for high air resistance & fans are relatively quiet
- Disadvantages: recirculation due to high air-entry and low air-exit velocities

Induced Draft Cooling Towers

- Two types
  - Cross flow
  - Counter flow
- Advantage: less recirculation than forced draft towers
- Disadvantage: fans and motor drive mechanism require weather-proofing

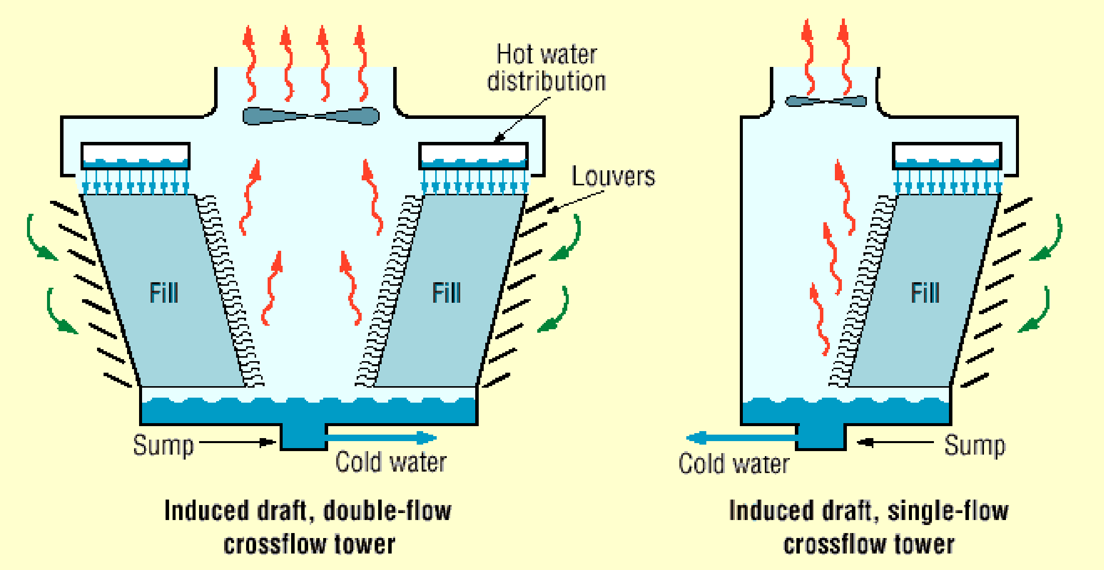
Induced Draft Counter Flow CT

- Hot water enters at the top
- Air enters at bottom and exits at top
- Uses forced and induced draft fans



Induced Draft Cross Flow CT

- Water enters top and passes over fill
- Air enters on one side or opposite sides
- Induced draft fan draws air across fill



Energy Efficiency Opportunities

1. Selecting a cooling tower
2. Fills
3. Pumps and water distribution
4. Fans and motors

Selecting a cooling tower

Capacity

- Heat dissipation (kCal/hour)
- Circulated flow rate (m3/hr)
- Other factors

Range

- Range determined by process, not by system

Approach

- Closer to the wet bulb temperature
- Bigger size cooling tower
- More expensive

Selecting a cooling tower

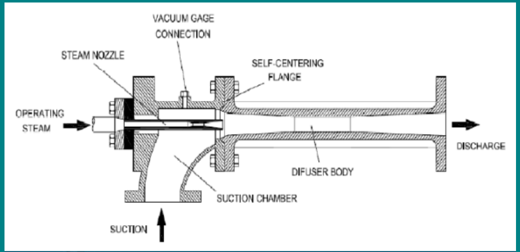
Heat Load

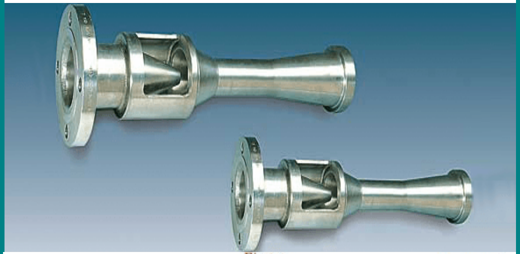
- Determined by process
- Required cooling is controlled by the desired operating temperature
- High heat load=large size and cost of cooling tower

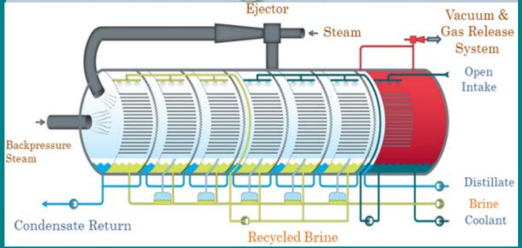
Wet bulb temperature –considerations:

- Water is cooled to temp higher than wet bulb temp
- Conditions at tower site
- Not to exceed 5% of design wet bulb temp
- Is wet bulb temp specified as ambient (preferred) or inlet
- Can tower deal with increased wet bulb temp
- Cold water to exchange heat

Steam Ejector

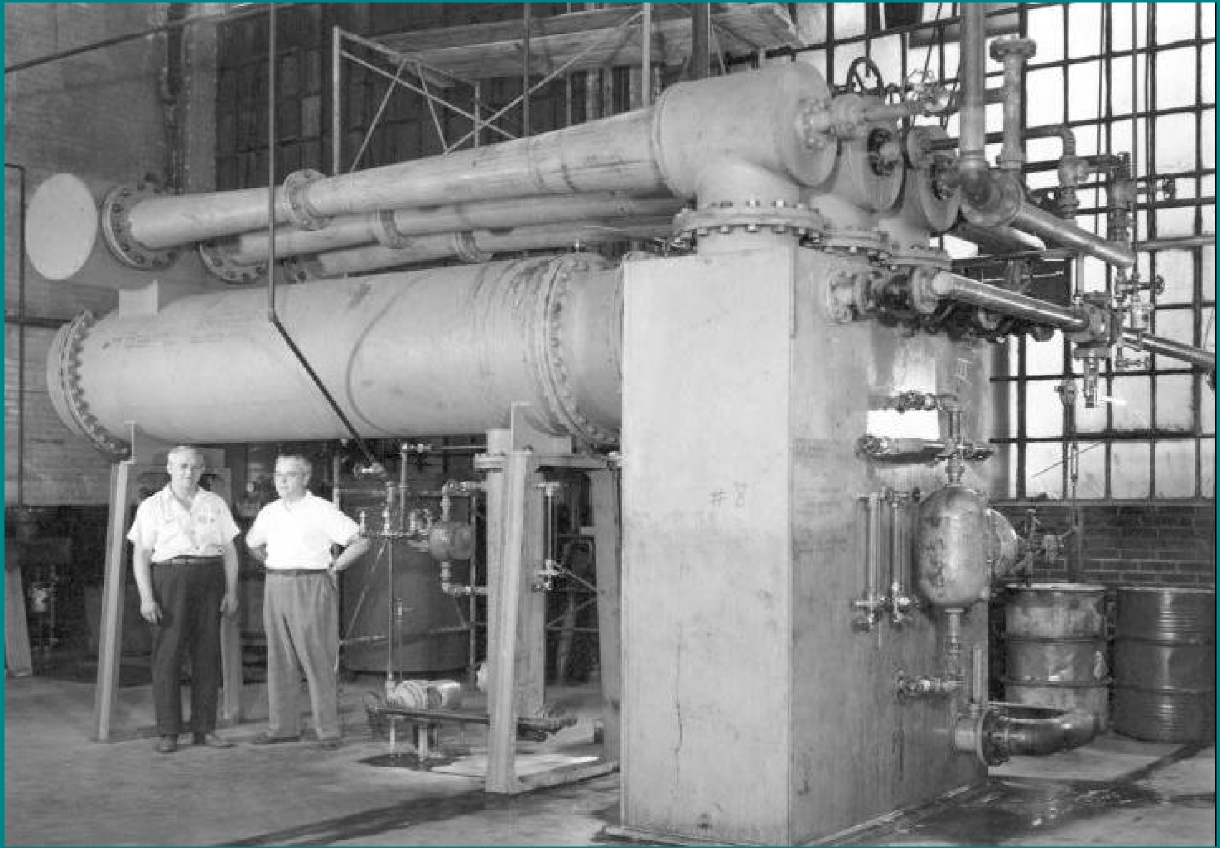




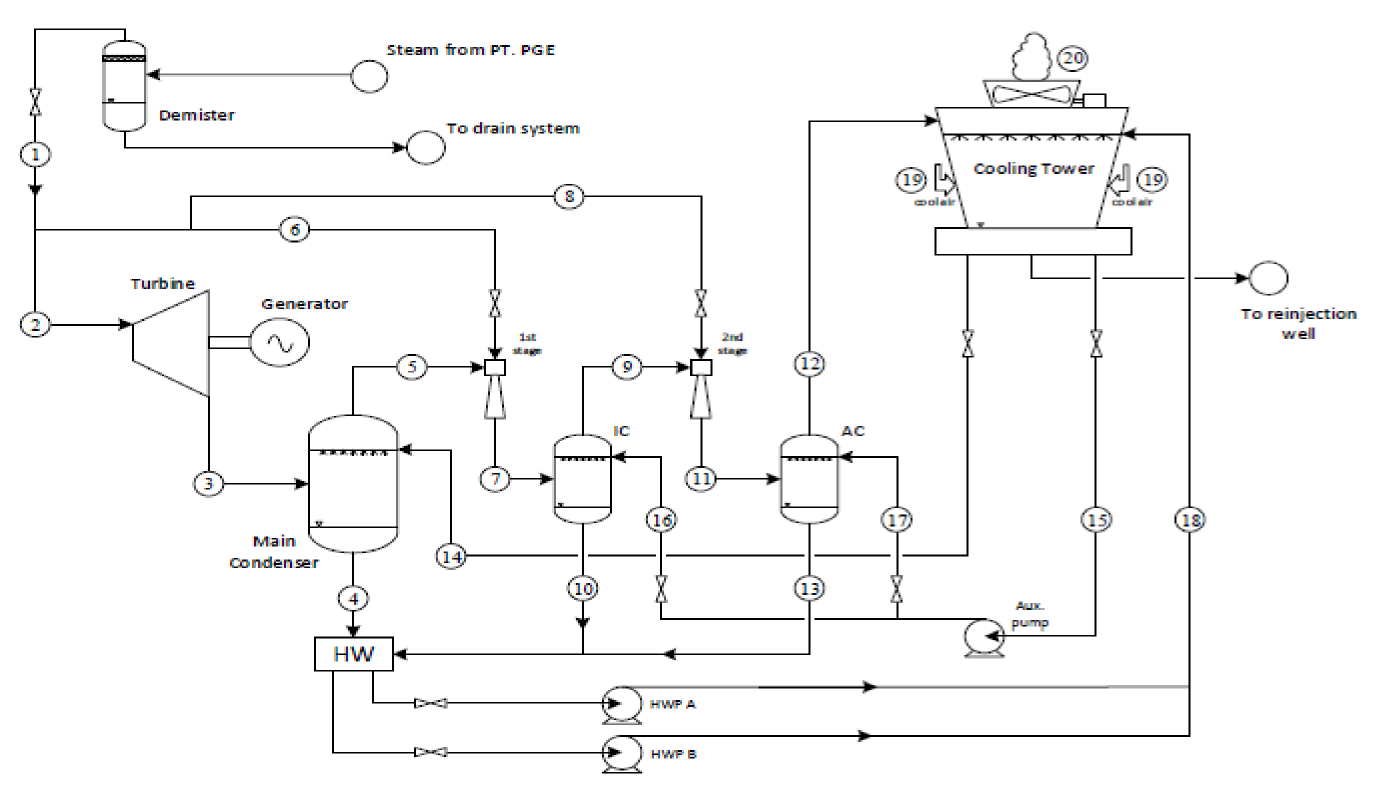


- The utilization of geothermal fluid for power generation is always related with non-condensable gases (NCGs) like CO_2, H_2S, NH_3, which are natural components of geothermal brine.
- After the separation process the steam can contain from 0,1[%] to even more than 20[%] of NCGs by weight of steam.
- The presence of non-condensable gases has no major negative impact until the fluid reaches the condenser, in which the steam is cooled and condensed to be pumped out of the system.
- Nevertheless as NCGs do not condense, if are not extracted the heat transfer efficiency of the condenser is reduced and a build-up in the pressure is created, which reduces the turbine efficiency, decreasing the total power output of the power plant.

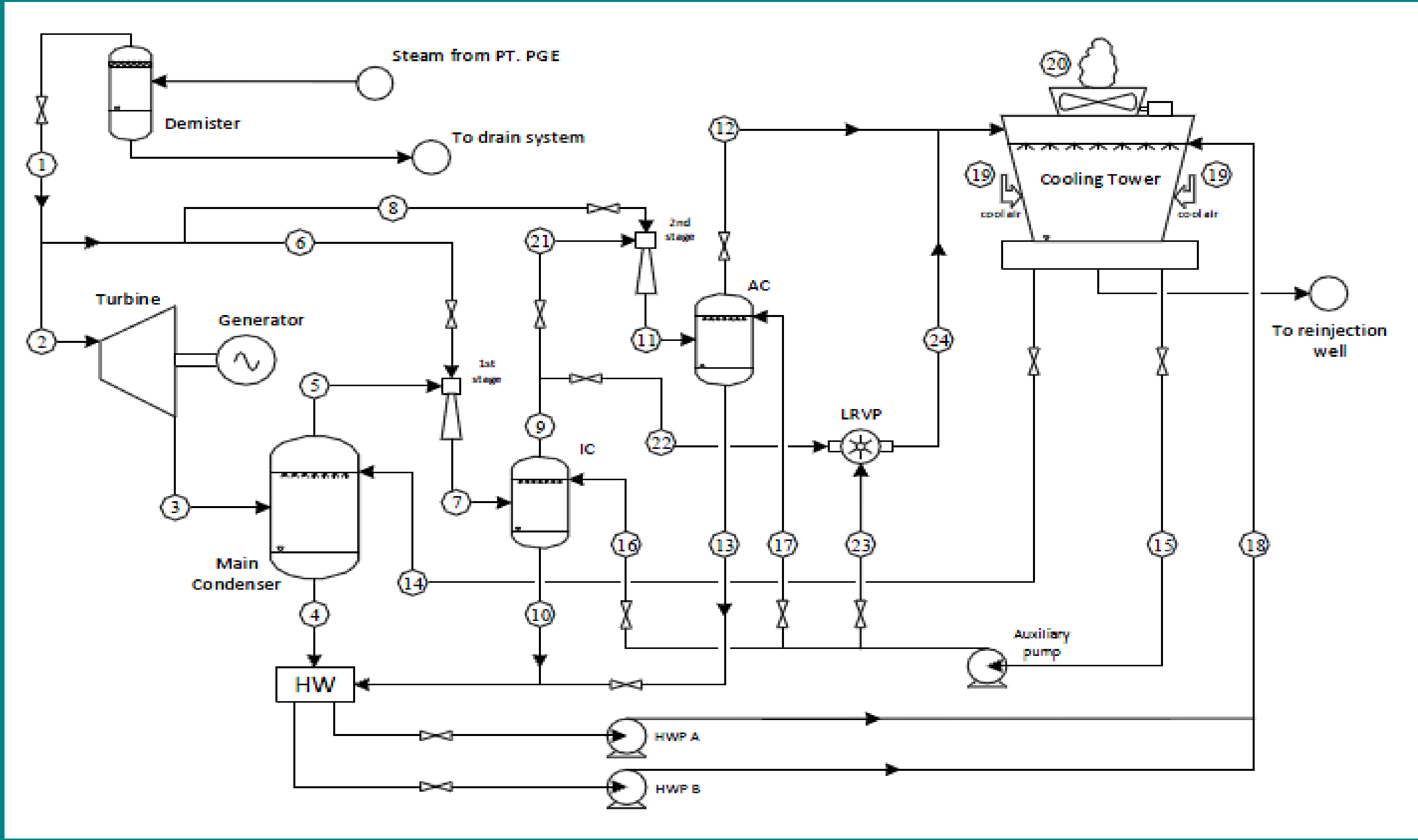
- Due the high water solubility of gases as carbon dioxide and hydrogen sulfide, corrosion in piping and equipment can be produced if the gases are not removed from the condenser, for these reasons the gas extraction system becomes a critical power plant equipment.
- As the typical condenser pressure is close to 0,1 [bar-a] or even less, is required to create a higher vacuum to extract the NCGs from the condenser, this increases the power plant cost due the requirement of a gas extraction system and also the operational cost due the auxiliary power and maintenance associated with these equipment.
- In practical applications there are three major equipment available for gas extraction: Steam ejectors, liquid ring vacuum pumps, and centrifugal compressors.
- Normally these are combined in hybrid systems or in several stages with intercooling to obtain better results.



Double Stage Steam Jet Ejector System



Hybrid System



Equipment List

Wellhead, brine and steam supply system

- Wellhead valves and controls
  - Blowout preventer (while drilling)
  - Master valves
  - Bleed lines
- Separator vessels
  - Vertical cyclone type
  - Bottom-outlet steam discharge
  - External or integral water collecting tank
- Ball check valves
- Steam piping, insulation and supports
  - Condensate traps
  - Expansion loops or spools
- Steam header
- Final moisture remover
  - Vertical demister
- Atmospheric discharge silencers
  - Rock mufflers or cyclone silencers with weir flow control
- Brine piping, insulation and supports

Turbine-generator and controls

- Steam turbine-generator with accessories
  - Multistage, impulse-reaction turbine
    - Inter-stage moisture removal (optional)
    - Single-cylinder, single-flow or double-flow
    - Tandom-compound, four-flow
  - Rotor material: stainless steel (typ. 12% Cr, 6% Ni, 1.5% Mo)
  - Blade material: stainless steel (typ. 403, 13% Cr)
  - Stator material: carbon steel
  - Direct coupled, hydrogen or air cooled, two-or four-pole synchronous generator with static excitation
  - Lubricating oil system

- Control system

    Digital-computer-based distributed control system
    Continuous data acquisition system
    Programmable component controller
    Full automation and remote control (optional)

- Air compressor

    One or two stage, motor driven units for plant and/or instrument air

Condenser, gas ejection and pollution control (where needed)

- Condenser
  - Direct-contact or surface-type
  - Barometric or low-level jet type
  - Integral gas cooler
- Condensate pumps and motors
  - Vertical, centrifugal can pumps
  - Stainless-steel wetted surfaces
  - Low-head, high volume design
  - Two 100 percent capacity units
  - Electric-motor driven
- Gas removal system
  - Steam jet ejectors with inter-and after-coolers
  - Turbocompressors
  - Hybrid ejector/compressor
- NCG treatment system
  - H2S removal via commercially available methods

Heat rejection system

- Water cooling tower
  - Multi-cell, mechanically-induced-draft, counterflow or crossflow type
  - Natural-draft type (rarely used)
  - Drift eliminator
  - Fire-retardant materials of construction

- Cooling water pumps and motors
  - Vertical, centrifugal, wet-pit type
  - Stainless steel wetted surfaces
  - Low-head, high-volume flow type
  - Four 25 percent or two 50 percent capacity units
  - Electric-motor driven

- Cooling water treatment system
  - Chemical additives to control pH to 6.5–8.0.

Back-up systems

- Standby power supply
  - Back-feed from grid
  - Diesel generator

Noise abatement system (where required)

- Rock mufflers for stacked steam
- Acoustic insulation for noisy fluid handling components

Geofluid disposal system

- Injection wells for excess condensate and cooling tower blowdown
- Emergency holding ponds for wells and separators
  - Impermeable lagoons for temporary disposal of waste brine

Thank You