Method and Techniques in Geothermal Power Plant Training

INTRODUCTION TO POWER PLANT COMPONENTS

Presented by Jooned Hendrarsakti

Simple Schematic of Geothermal Power Plant

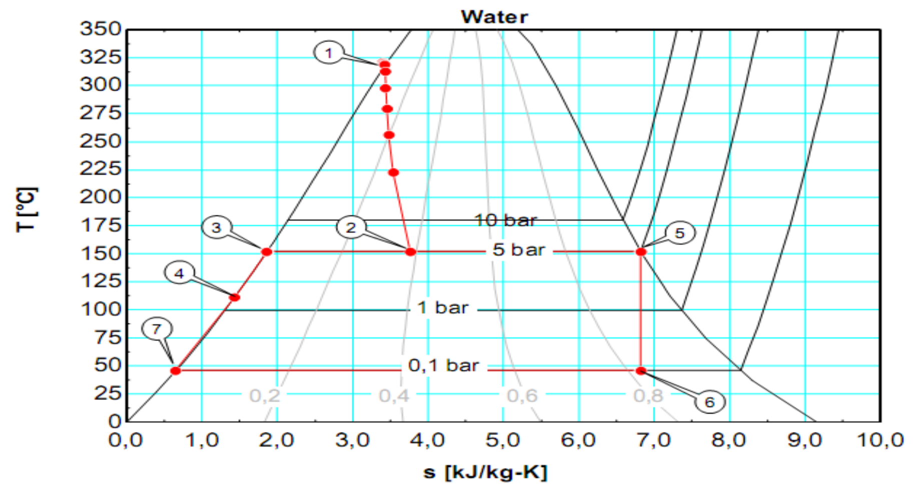
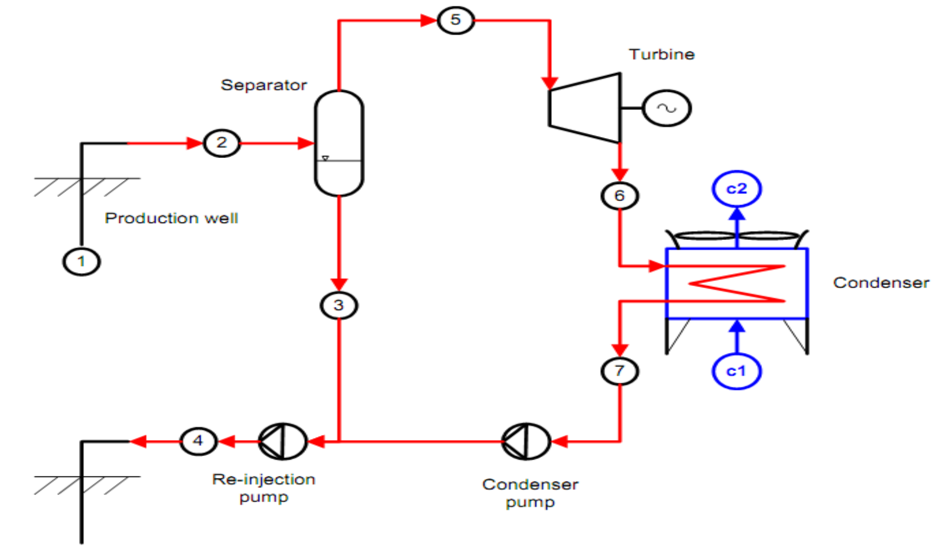
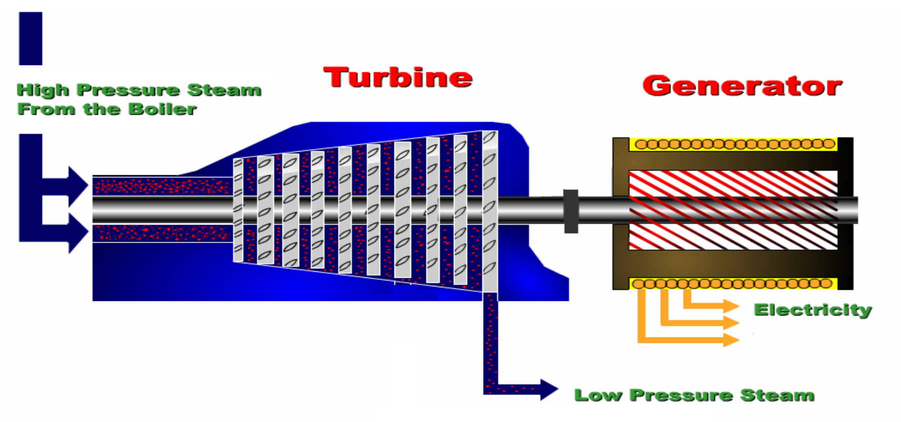


FIGURE 2: T-s diagram of a single flash cycle



Turbine

- steam is admitted to the turbine
- heat energy is converted into mechanical energy – useful work
- high pressure turbine
- low pressure turbine



Turbin Isentropic Efficiency

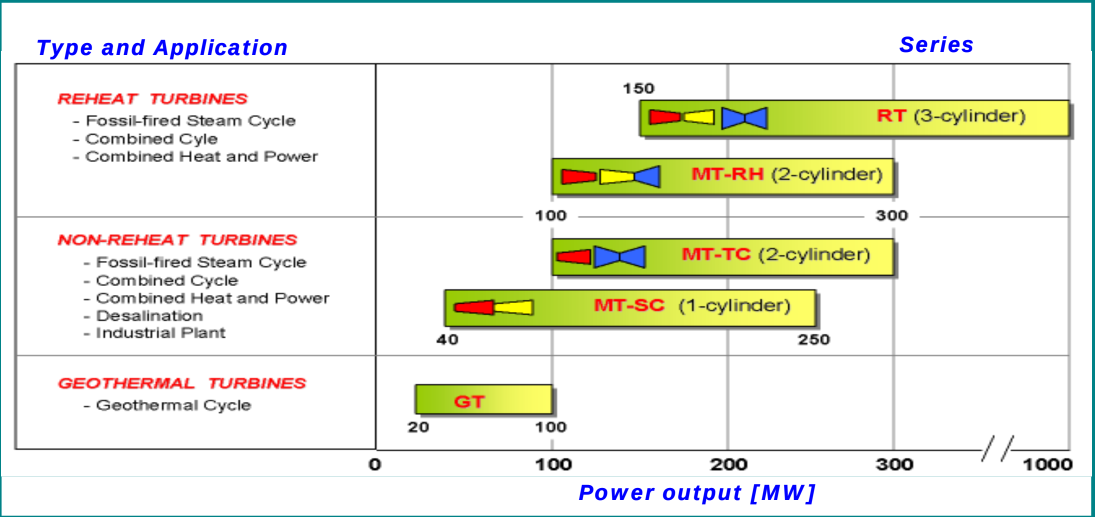
- Ideal turbine is isentropic similar (given by manufacturer)
- Non-ideal has isentropic efficiency
- Real turbin enthalpy = $h_2=h_1-\eta(h_1-h_{2s})$
- Work output, $W= m(h_1-h_2)$
- Expansion may result in wet region: erosion and blade damage
- the efficiency of a steam turbine is limited by the maximum temperature of the steam produced and is not directly a function of the fuel used (for the same steam conditions, coal, nuclear and gas power plants all have the same theoretical efficiency)

Basic Glossary

- Operating pressure
- Heating surface
- Generating surface

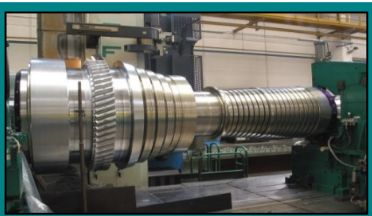
Steam Turbines

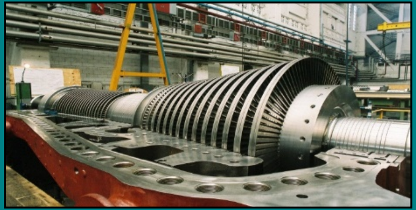
Product Line



References as of December 2009

Application	Units	MW
Fossil fuelled power plants	347	66,900
Combined cycles	105	8,275
Cogeneration power plants	607	5,825
Geothermal power plants	130	2,118
Nuclear	12	6,180
New Units Total	1,201	89,298
Retrofits	33	7,476

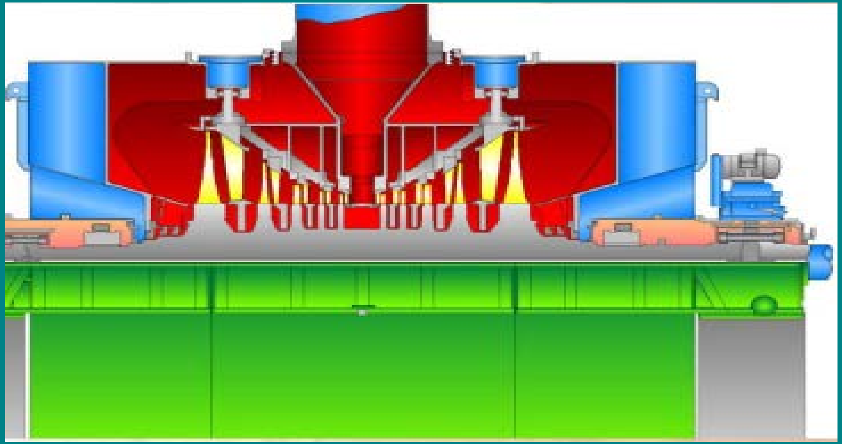




TURBIN DESIGN

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, nozzles and blades
- High quality rotor forgings to limit impurities and reduce likelihood of SCC
- HVOF alloy or ceramic blade coatings to resist erosion



Steam Turbine Blades

- Steam turbine blades are subjected to high thermal stresses.
- Made of Ni-chrome steel.

Stator & Rotor

- Steam enters in the stator and then enters into the rotor.

- The pressure drop occurs in stator for impulse turbines where as for reaction turbines pressure drop occurs in both stator and rotor.

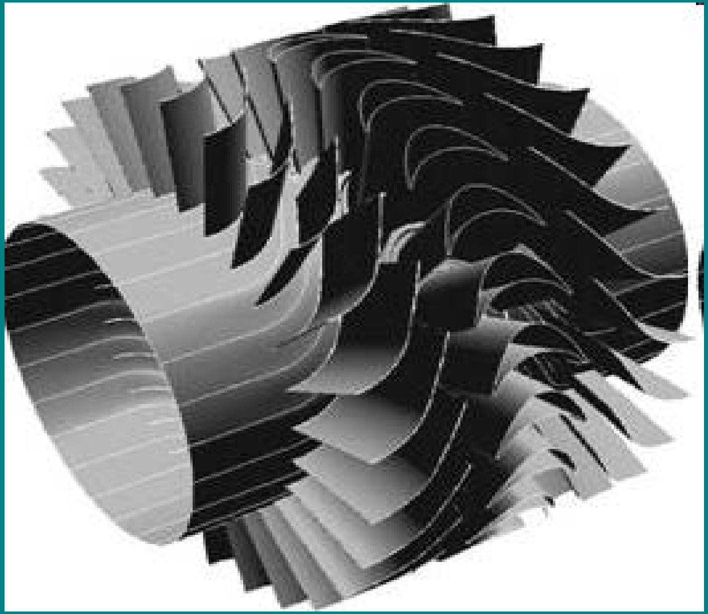
- Work is produced in the rotor by the steam because of a reduction in its pressure (reaction turbine) and a change in the direction of its velocity (reaction and impulse turbines).

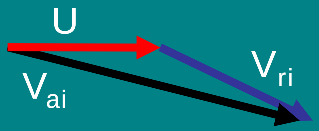
- High velocity steam is allowed to blow on to curved blade, steam will suffer a change in direction as it passes across the blade and leaves.

- As a result of its change in direction across the blade, the steam will impart a force to the blade resulting rotation of shaft on which blades are fixed.

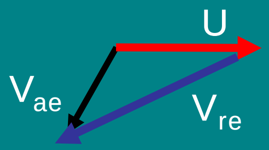
Velocity triangles

Steam enters axially and leaves axially (generally in axial-flow steam turbines)

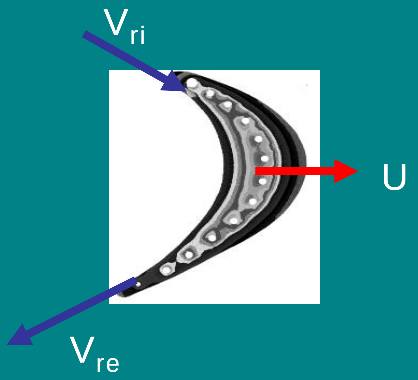




Inlet Velocity Triangle



Exit Velocity Triangle



The velocity of the fluid approaching the bucket = V_{ai} .
The velocity of the bucket = U.
The velocity of the approaching fluid to relative the bucket velocity is $V_{ri} = V_{ai} - U$
The velocity of the outlet fluid relative the bucket velocity is $V_{re} = k(V_{ri})$
(k being a friction loss factor)
The velocity of the fluid in the direction of bucket movement -> is the whirl velocity.
The outlet whirl velocity V_{ae} is simply given by, $V_{ae} = U - V_{re}(\cos(\pi - \theta))$

Work Done / kg of steam

Work done / kg of steam is called specific work out put of turbine

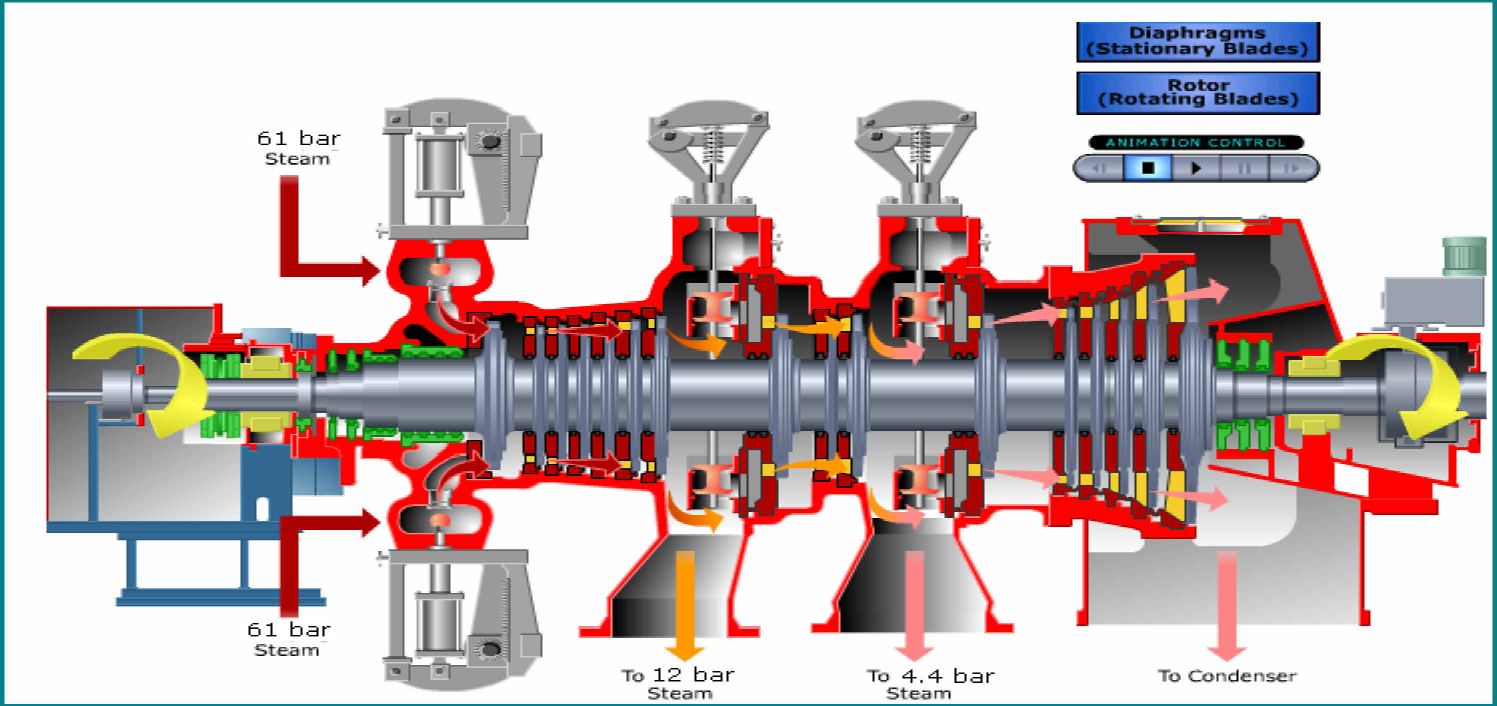
$$\boxed{W.D/kg = U * (V_{ai} + V_{ae})}$$

Where: U = Blade Velocity
V_{ai} = Whirl velocity at inlet
V_{ae} = Whirl velocity at outlet

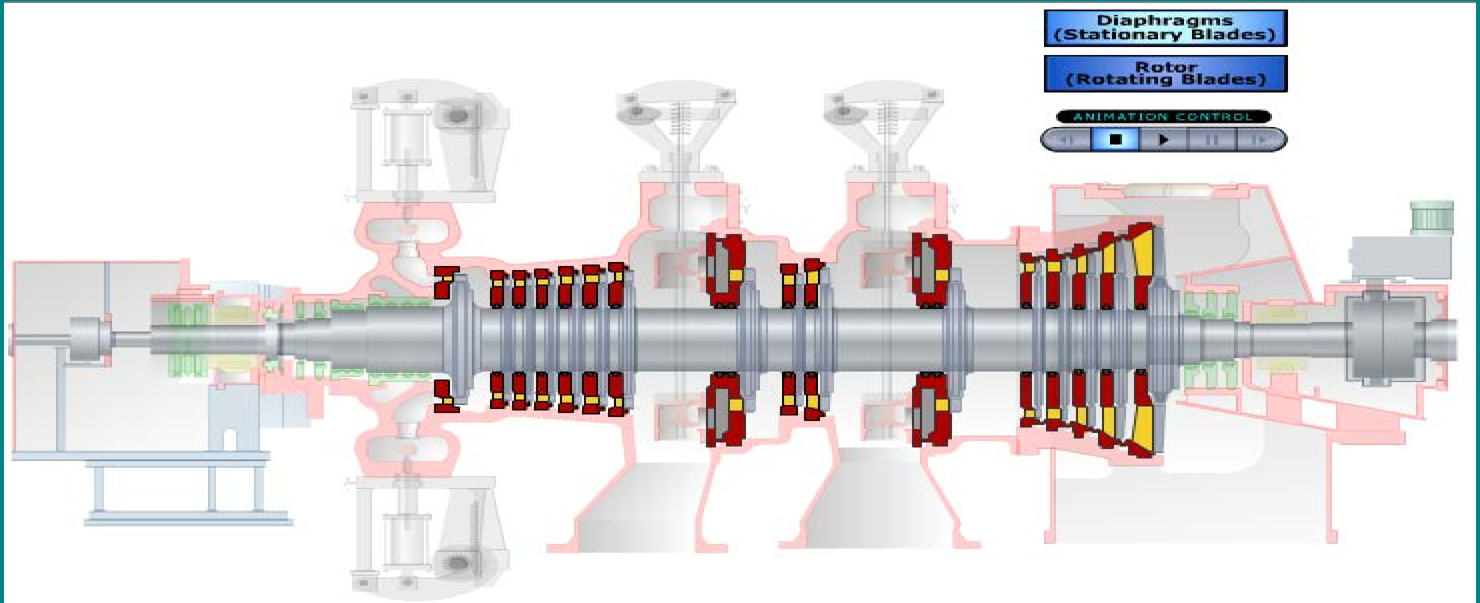
$$\boxed{\text{Power output} = M_s * [U * (V_{ai} + V_{ae})]}$$

Where : M_s = Mass flow rate of steam in kg/s = [ρ * Q]
ρ = density (kg/m^3)
Q = Volume flow rate (m^3 /s)

User interface For simulation of Steam turbine

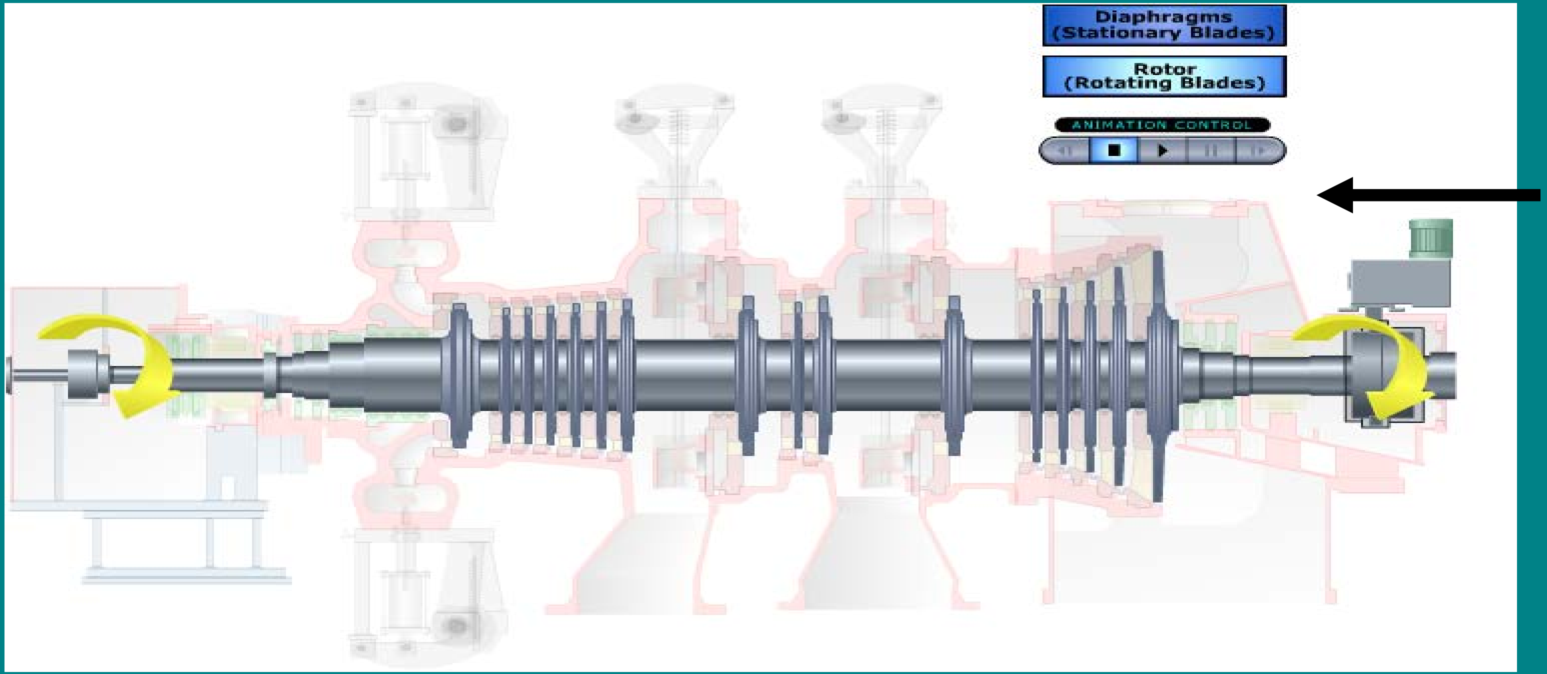


Operation 1



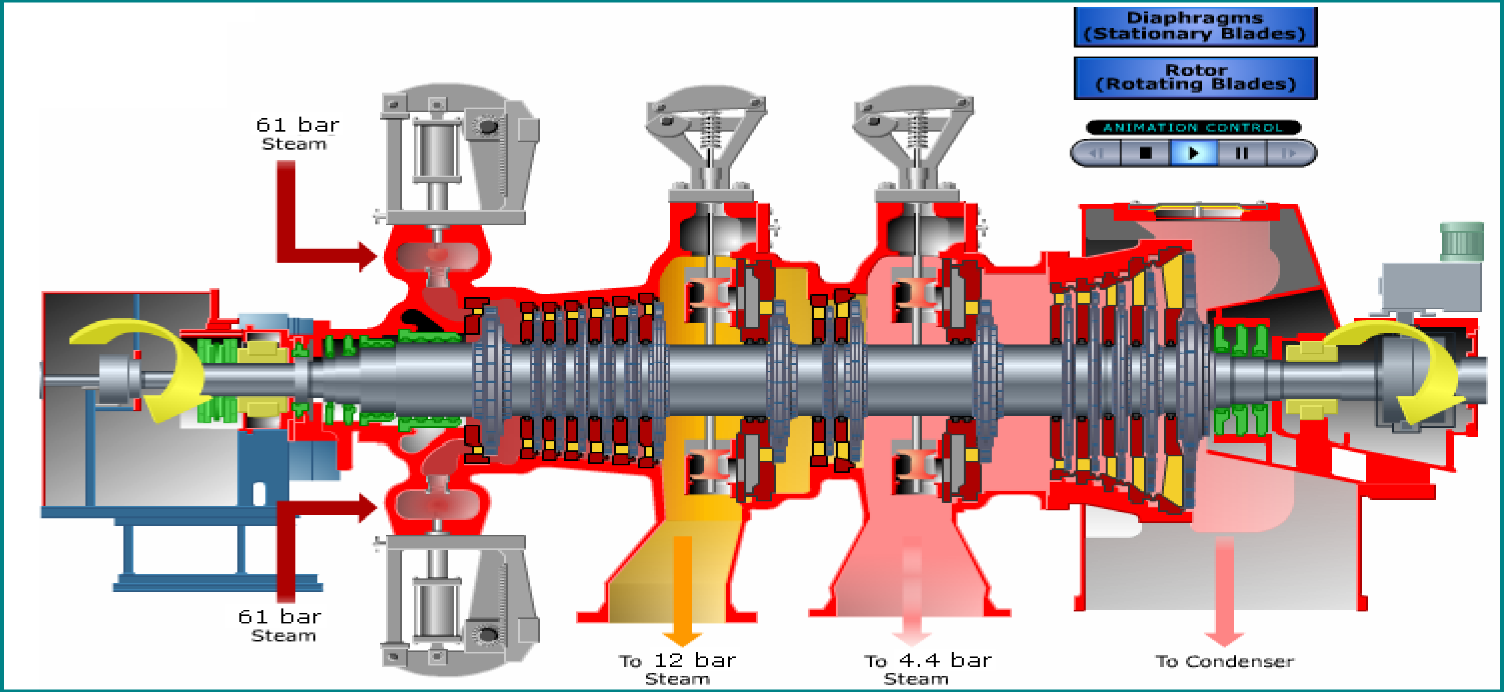
Diaphragms
(Stationary Blades)
Rotor
(Rotating Blades)
ANIMATION CONTROL

Operation 2



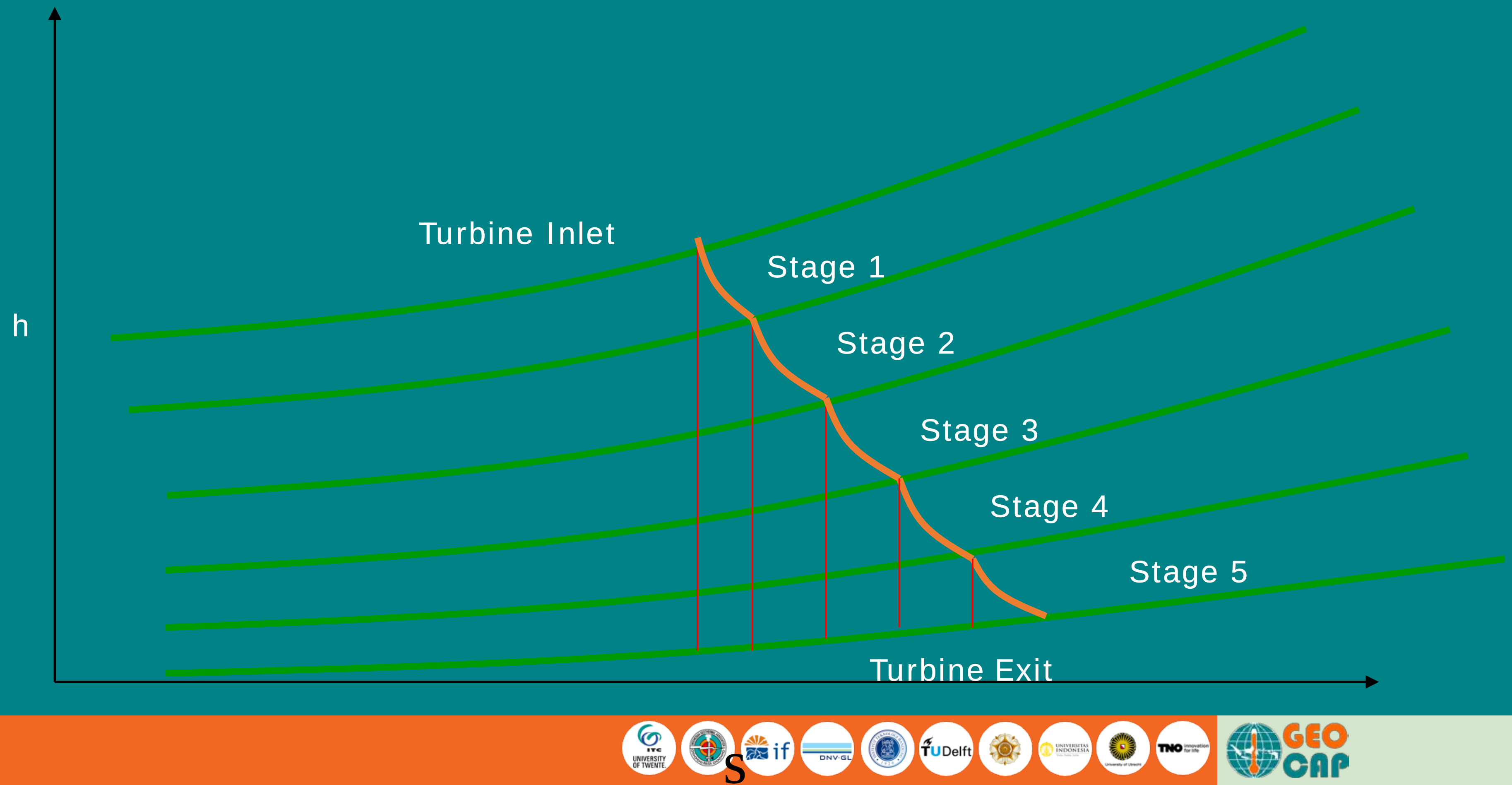
Reference : http://atd.na.amec.com/flash_power.html

Operation 3

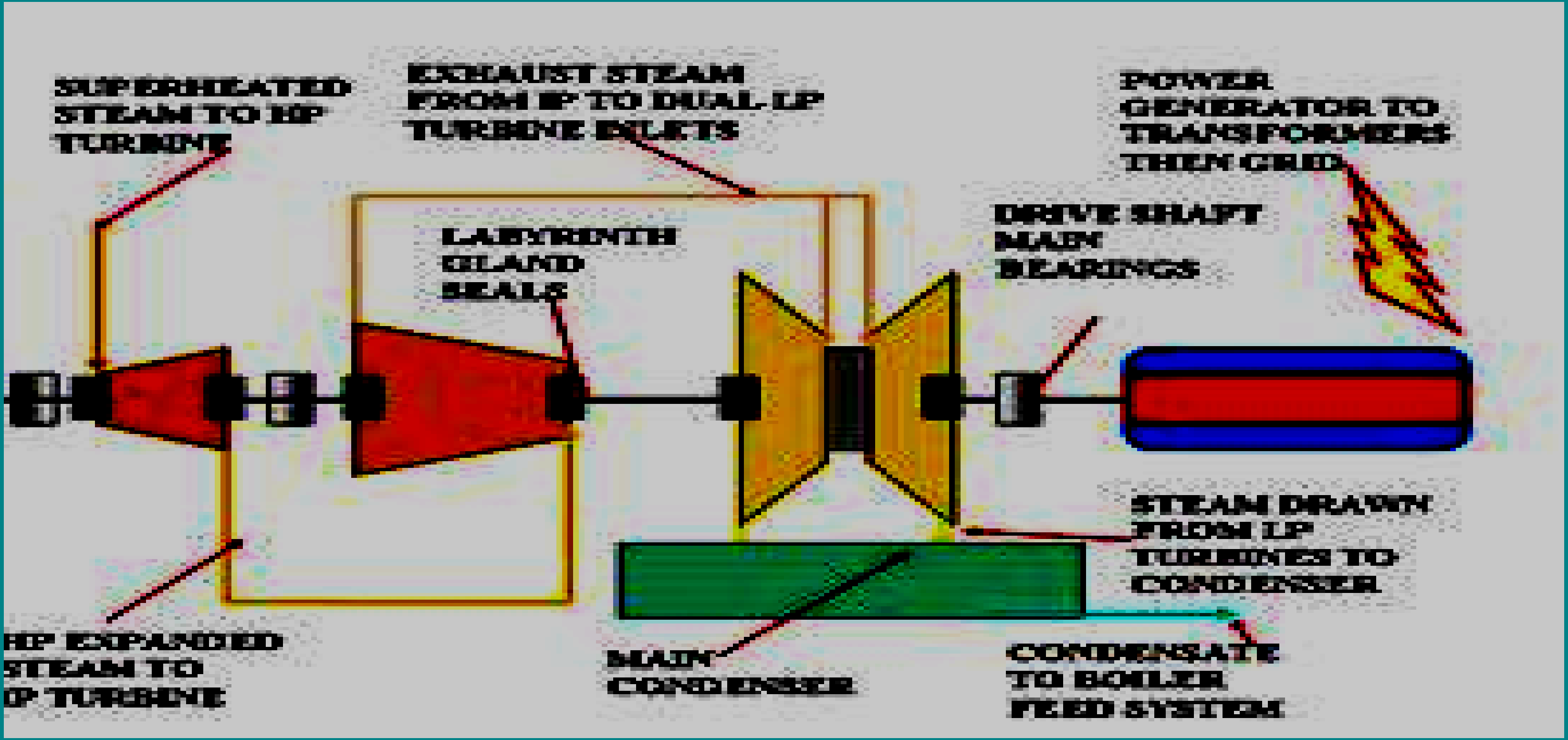


Diaphragms (Stationary Blades)
Rotor (Rotating Blades)
ANIMATION CONTROL
61 bar Steam
61 bar Steam
To 12 bar Steam
To 4.4 bar Steam
To Condenser

Enthalpy Entropy Diagram for Multistage Turbine

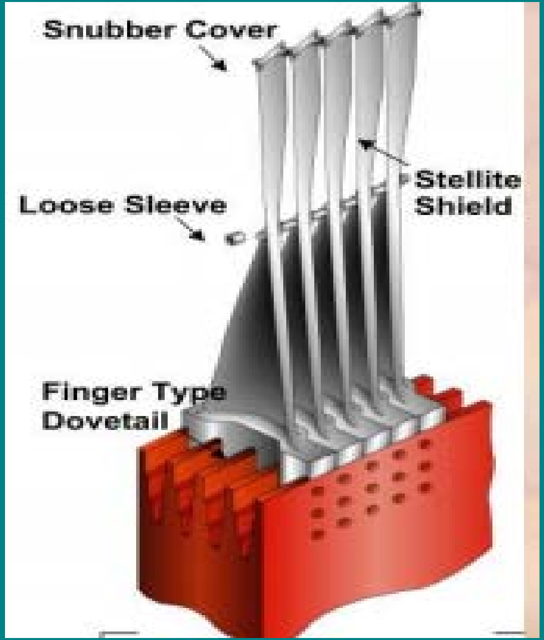


Tandem Reheat Steam Turbine



TURBIN CONFIGURATION

- Impulse or reaction blading
- Special design features due to saturated steam inlet conditions. Exhaust very wet, require high evels of inter-stage condensate drainage.
- Latest designs have drain removal grooves on trailing edge to promote removal of large drops from steam path
- Integral blade snubbers at the outer edge that bear on each other to damp out blade vibrations
- Loose sleeve and forged lug at blade mid span on long blades to further improve damping
- Stellite on leading edges of last rows due to moisture impingement

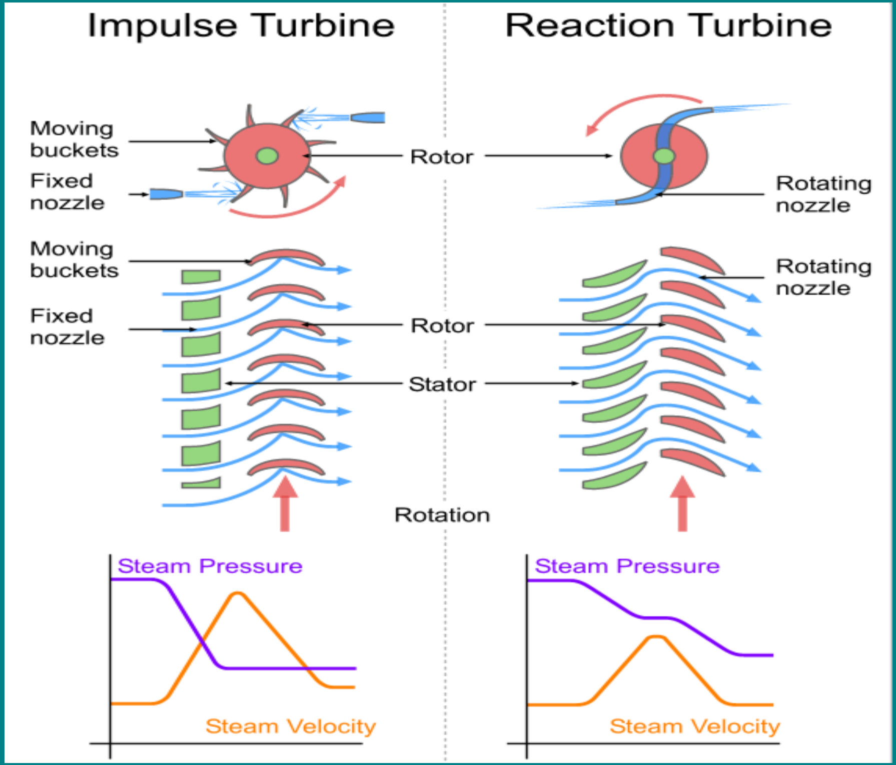


Impulse & Reaction Turbines

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.



Reaction Turbine

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 onto 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: 1. Journal bearings → Front journal bearing, Rear rournal bearing

   2. 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.

Principal Parts of Turbine (continue)

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.

Turbine Accessories

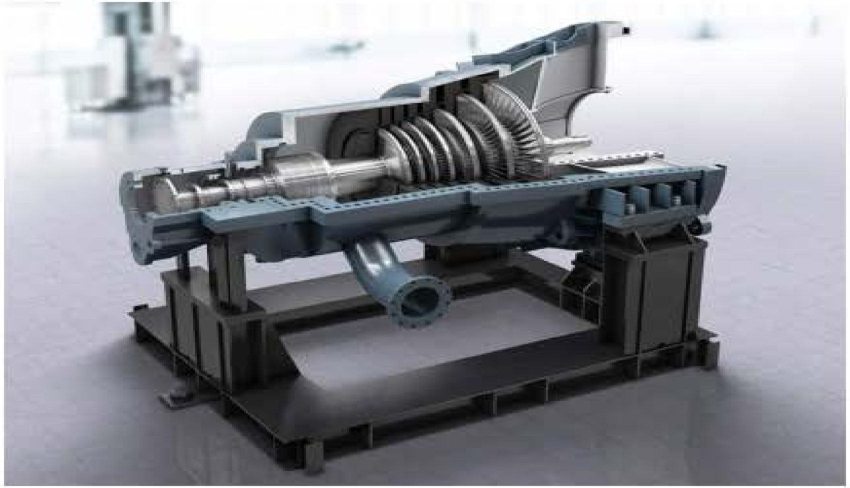
1. Oil pumps
2. Oil cooler
3. Gland steam condenser
4. Surface Condenser
5. Steam jet air ejector
6. Condensate extraction pumps
7. HP Heaters
8. LP Heaters

Industrial Steam Turbine – SST-400 GEO

SIEMENS

Key Values

Power output	5 to 50 MW
Speed	3,000 to 6,000 rpm
Live Steam Parameters	
Inlet Pressure	≤ 15 bar / 218 psi
Inlet Temperature	≤ 250 °C / 482 °F
Exhaust conditions	
Condensing	≤ 0.4 bar / 5.8 psi
Non-condensing	up to 1.4 bar / 20 psi
Applied for	Geothermal plants



The SST-400 GEO is a derivative of the SST-400, optimized for the harsh conditions of geothermal steam cycles.

Simple Schematic of Geothermal Power Plant

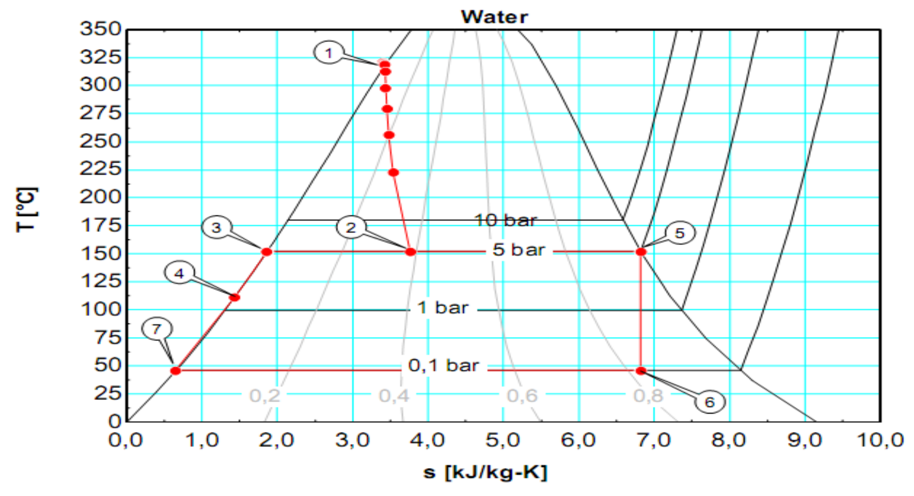
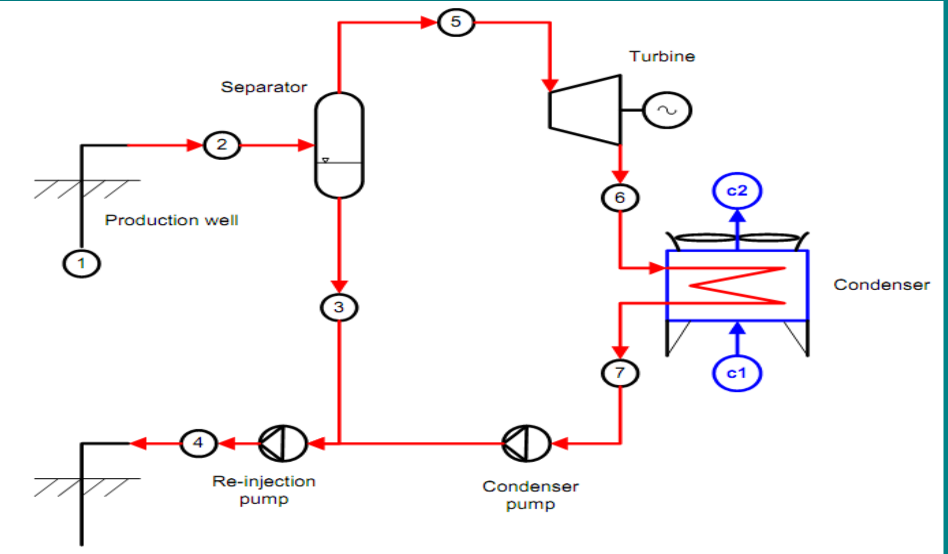


FIGURE 2: T-s diagram of a single flash cycle

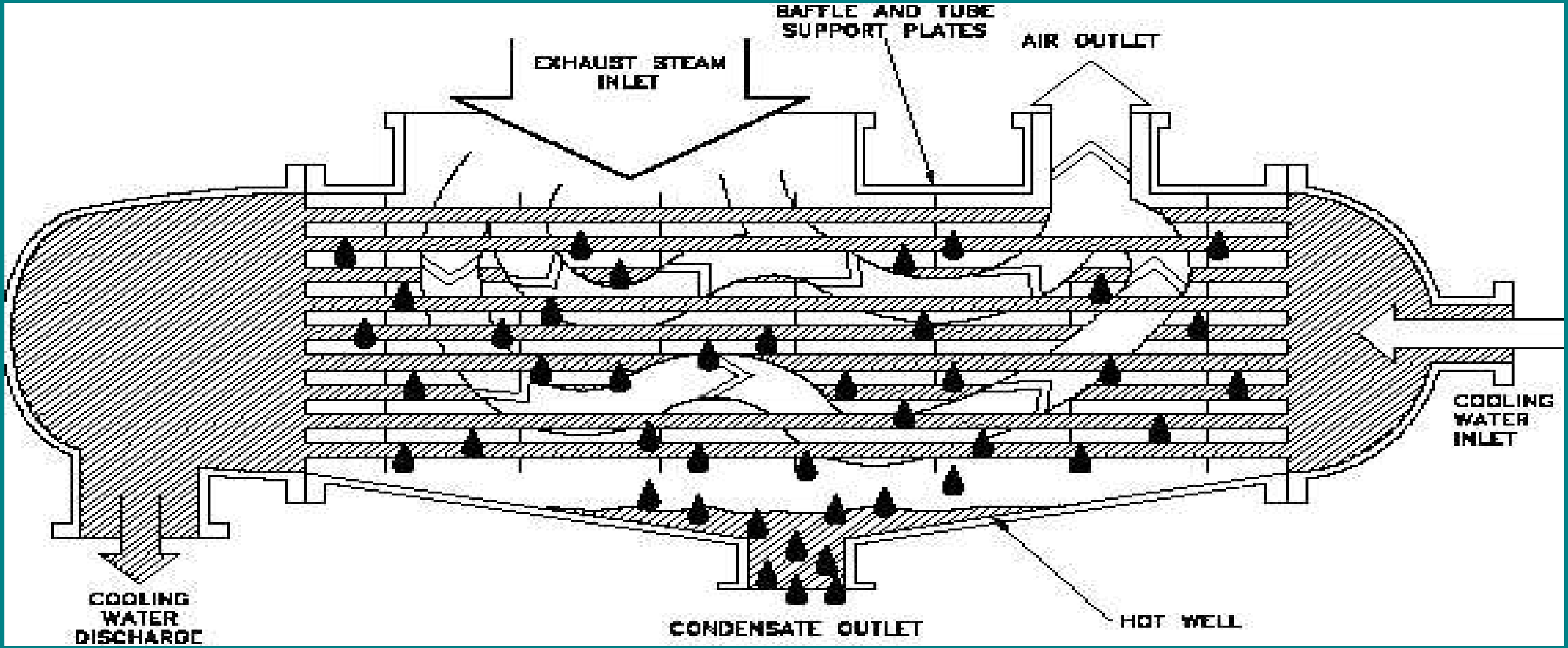


Condenser as a Heat Exchanger

Heat Exchanger:

- Vacuum is created due to steam / condensate volume difference
- Vacuum is maintained by constant cool water circulation through the tubes

Condenser



BAFFLE AND TUBE
SUPPORT PLATES
AIR OUTLET
EXHAUST STEAM
INLET
COOLING
WATER
INLET
COOLING
WATER
DISCHARGE
CONDENSATE OUTLET
HOT WELL

Auxiliaries

- CONDENSATE – COLLECTING TANK (HOTWELL)
- MAIN CONDENSATE PUMP
- AIR EJECTOR
- DEAERATING FEED TANK
- MAKE UP TANK (EMERGENCY FEED TANK)
- FEED PUMP
- FEED HEATER
- ECONOMISER

Main Condensate Pump

- condensate – collecting tank (hotwell)
- Main Condensate Pump: To pump water from the hotwell through the main air ejector to the deaerating feed tank

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 multipass 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.

Steam Condenser Design

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 $C_{max} = m\, cp_{eff}\, 00$, *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) throughout the exchanger, including the case of phase changing fluids in assumption 6.

9. The specific heat of each fluid is constant throughout the exchanger, so that heat capacity rate on each side is treated as constant.

Steam Condenser Design

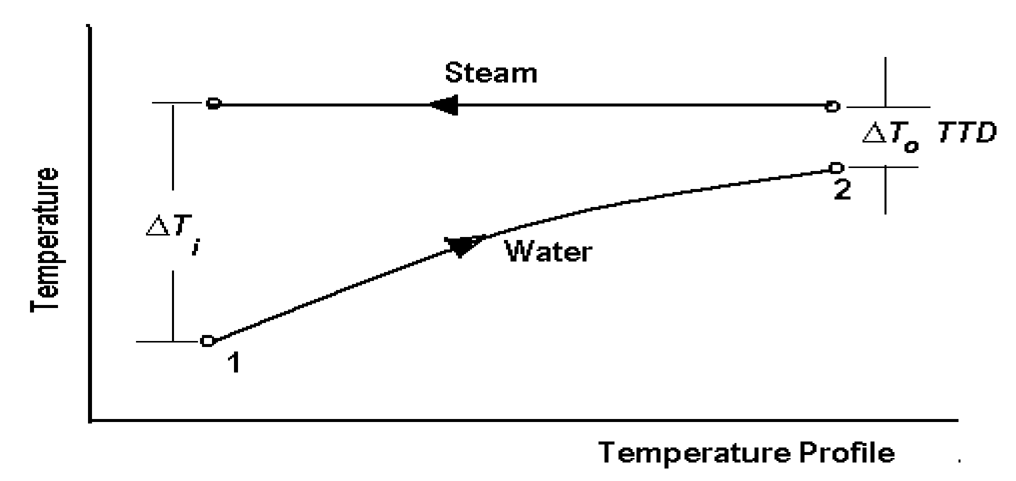
10. The heat transfer surface area *A is distributed uniformly on each fluid side in a* single-pass or multipass exchanger. In a multipass unit, the heat transfer surface area is distributed uniformly in each pass, although different passes can have different surface areas.

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, flow bypassing, or flow leakages occur in any stream. The flow condition is characterized by the bulk (or mean) velocity at any cross section

Condenser Design

H.T. Calculation



Heat Transfer

Dimensionless numbers and properties:

Prandalt number

$$\Pr = \frac{\nu}{\alpha} = \frac{\text{viscous diffusion rate}}{\text{thermal diffusion rate}} = \frac{\mu/\rho}{k/c_p\rho} = \frac{c_p\mu}{k}$$

Reynolds number

$$R_e = \frac{v \text{ X } d_i}{\mathrm{v}}$$

Heat transfer co-efficients

Inside boundary of tube:

$$\frac{h_i.d_i}{\mathrm{k}} = 0.023(R_e)^{0.8} \text{ X } (\Pr)^{1/3}$$

Outside boundary of tube

assume that outside heat transfer co-efficient is 1.5 times the inside heat transfer co-efficient

Overall heat transfer co-efficient:

$$\frac{1}{\mathrm{U_O}} = \left(\frac{r_o}{r_i}\right)\frac{1}{h_i} + \left(\frac{r_o}{r_i}\right)R_{fi} + \frac{r_o}{k}\ln\left(\frac{r_o}{r_i}\right) + R_{fo} + \frac{1}{h_o}$$

Heat Transfer

- $Q = UA\,\Delta T_m$

- $\Delta T_m = \dfrac{\Delta T_A - \Delta T_B}{\ln\left(\dfrac{\Delta T_A}{\Delta T_B}\right)} = \dfrac{\Delta T_A - \Delta T_B}{\ln \Delta T_A - \ln \Delta T_B}$

The overall H.T. coefficient *U* can also be expressed by the empirical Equation:

$$U = C_1 C_2 C_3 C_4 \sqrt{v}$$

Where C_1, C_2 , C_3 and C_4 are obtained from the tables

Heat Transfer

Constants in Equation

Tube outer diameter, in	3/4	7/8	1.0
C_1 [v m/s,U W/(m^2 . k)]	2777	2705	2582

Water Temp. ^oC	4	8	12	16	20	24	28	32	36	40
C_2	0.58	0.64	0.72	0.79	0.86	0.93	1.0	1.04	1.08	1.12

Tube material		304 stainless steal	Admiralty, Arsenic-copper	Aluminum-Brass, Muntz metal	Aluminum-Bronze, 90-10 Cu-Ni	70-30 Cu-Ni
C_3	18 gauge	0.58	1.0	0.96	0.9	0.83
	17gauge	0.56	0.98	0.94	0.87	0.80
	16 gauge	0.54	0.96	0.91	0.84	0.76
C_4 0.58 for clean tubes, less for algae or sludged tube						

Steam Condenser Design

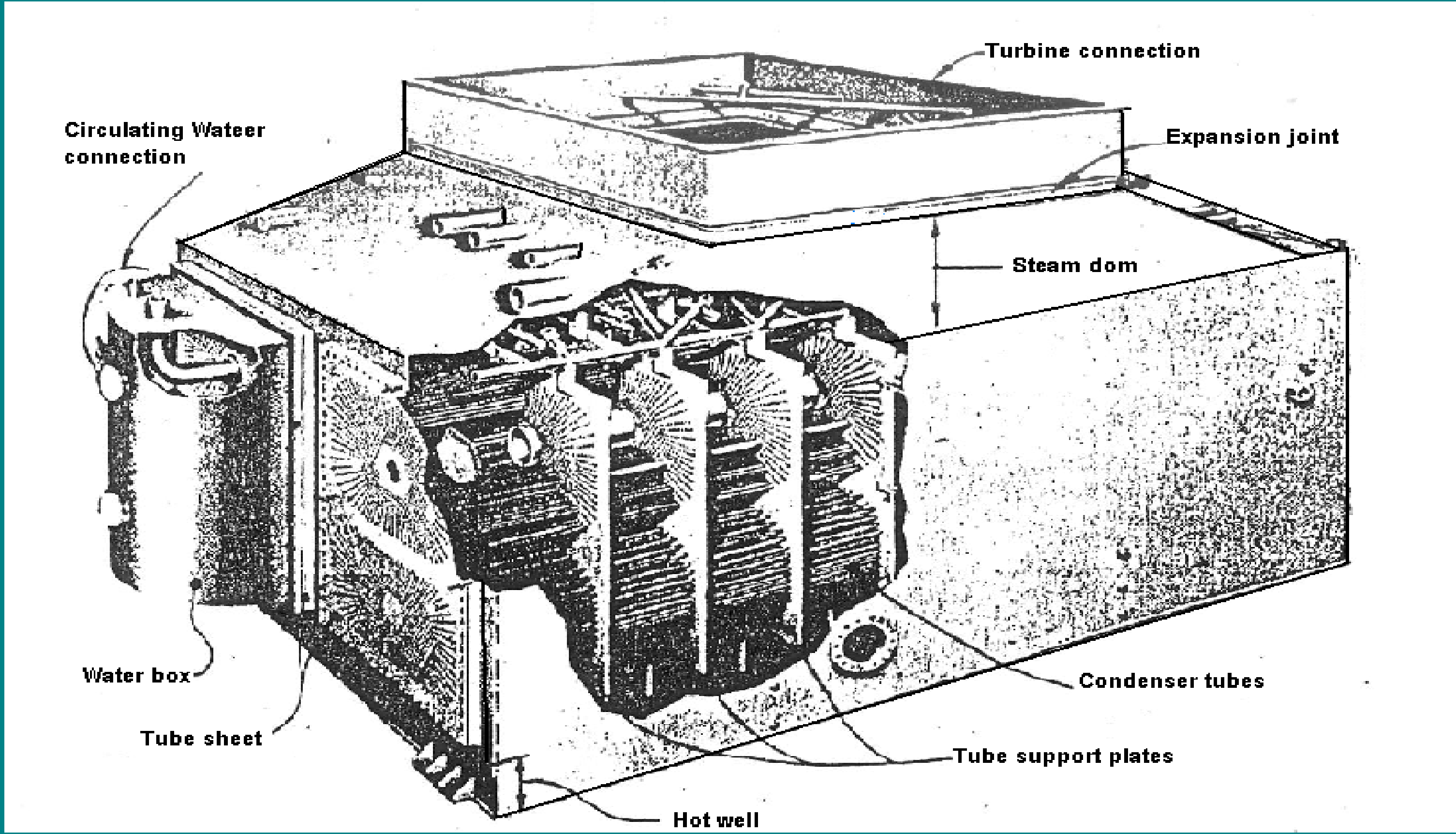
Surface area required

- $A = Q / U \, \Delta T_m$
- $A = (\pi d) \times l \times n$

Water calculation

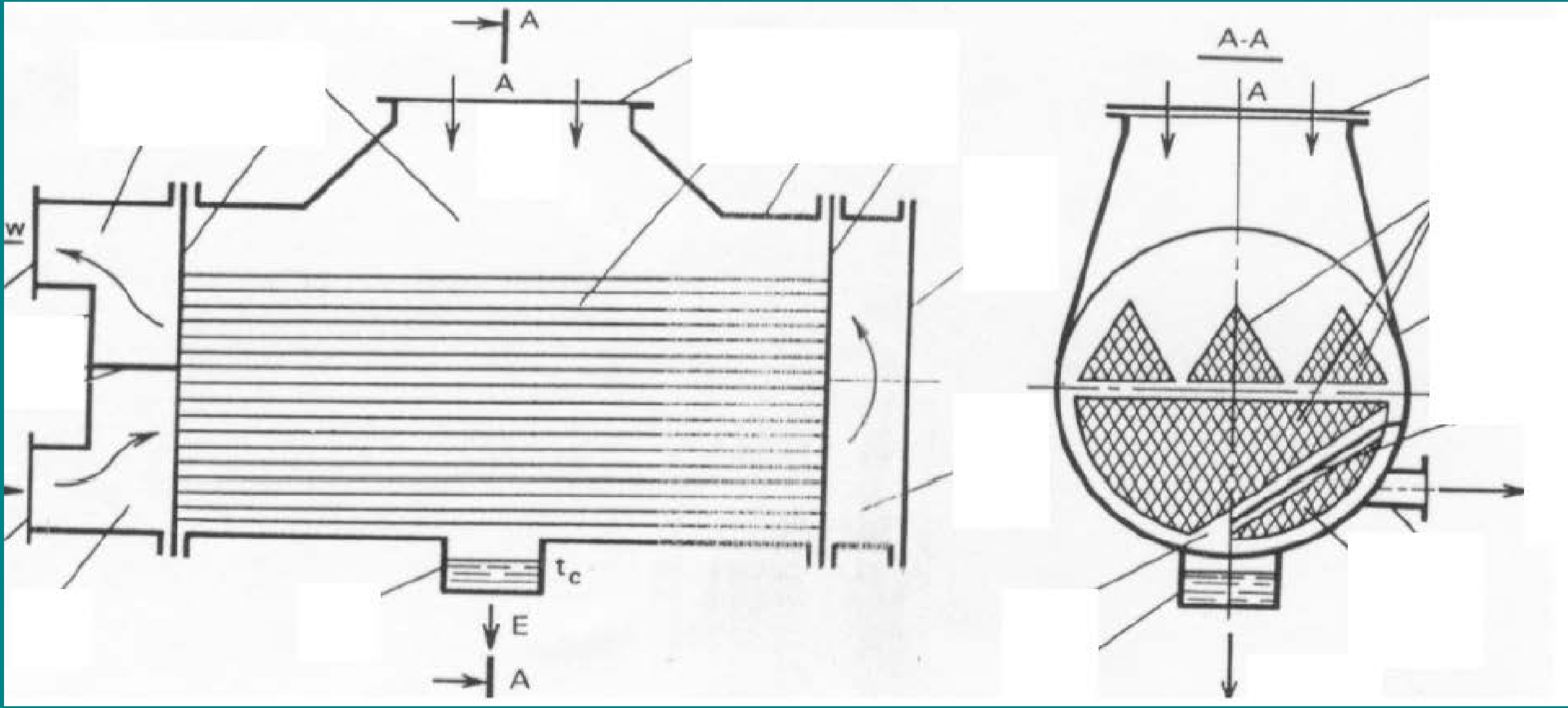
- $m_{w} = Q/cp\,(T_2 - T_1)$
- $T_2 - T_1 = \Delta T_i - \Delta T_o$

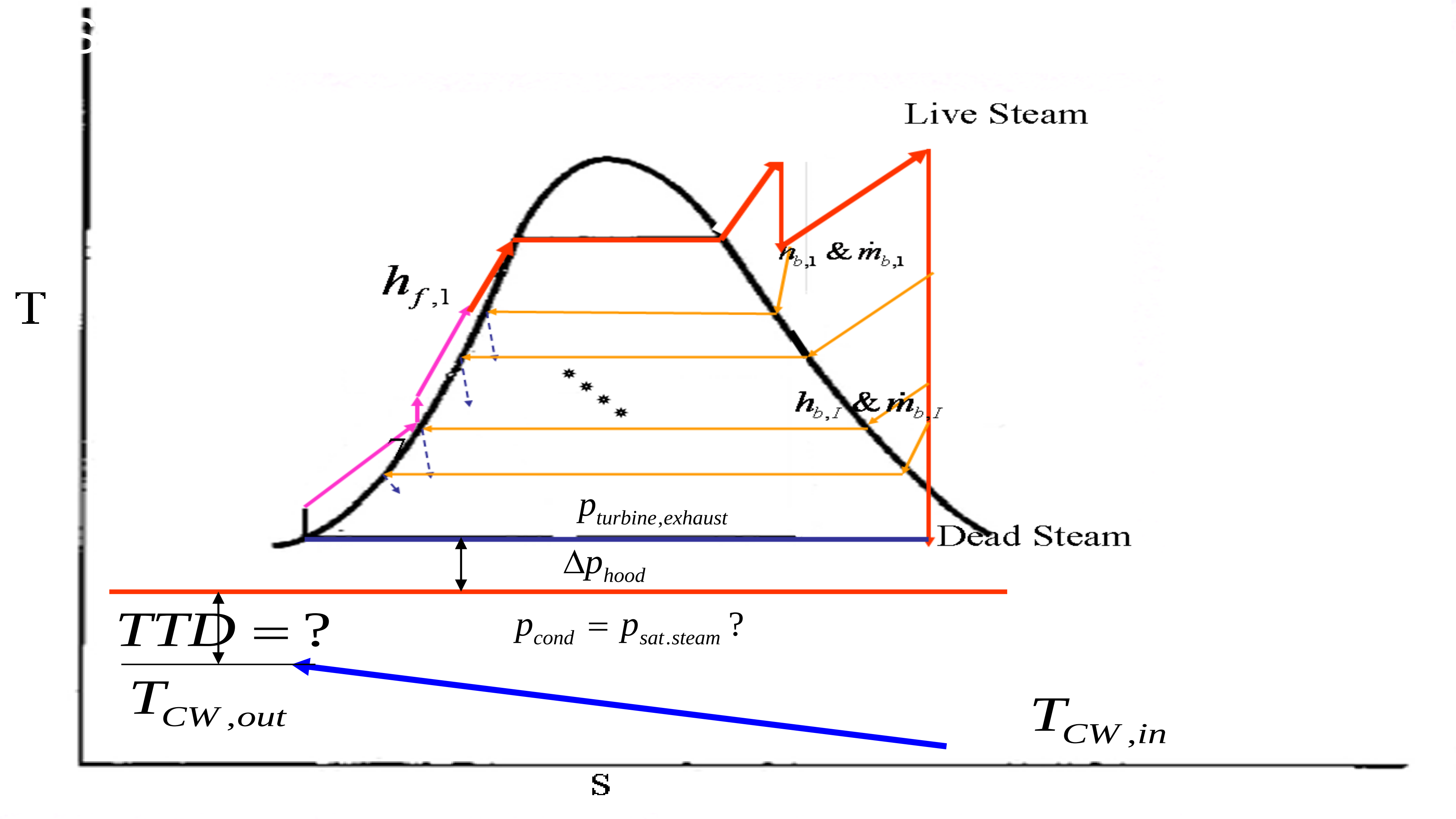
Where: $cp_{water} = 4.18$ kJ/kg ^oK



Turbine connection
Circulating Wateer connection
Expansion joint
Steam dom
Water box
Tube sheet
Condenser tubes
Tube support plates
Hot well

Two-Pass Surface Condenser





Live Steam
$h_{b,1}$ & $\dot{m}_{b,1}$
$h_{f,1}$
$h_{b,I}$ & $\dot{m}_{b,I}$
$p_{turbine,exhaust}$
Dead Steam
Δp_{hood}
$TTD = ?$
$p_{cond} = p_{sat.steam}$?
$T_{CW,out}$
$T_{CW,in}$
T
s

Thermal Processes Occurring in Condensers

- The condenser never receives pure seam from the turbine.
- A mixture of steam and non-condensable gases (Air-steam mixture) enters the condenser.
- The ratio of the quantity of gas that enters the condenser to the quantity of steam is called the relative air content.

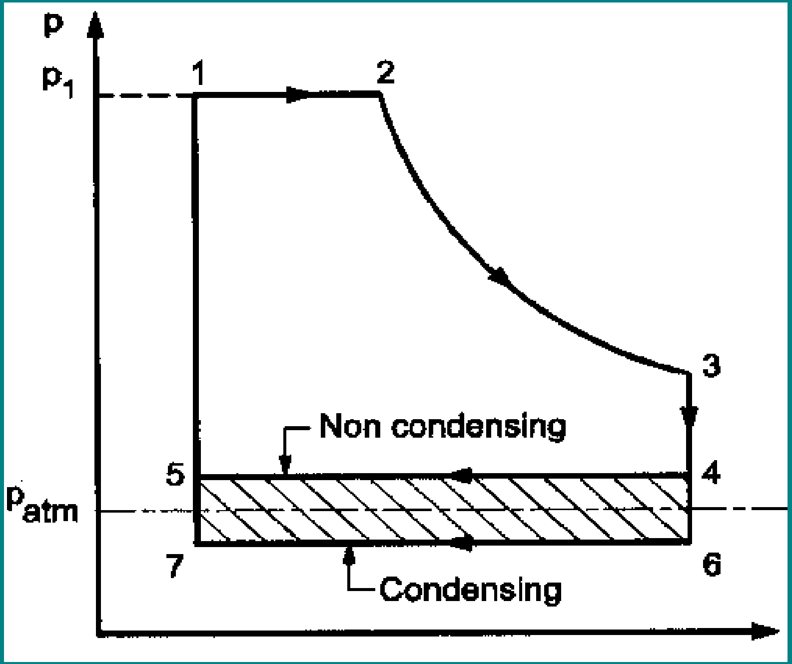
$$\varepsilon = \frac{\dot{m}_{air}}{\dot{m}_{c,s}}$$

The value of ε, depends on type, capacity, load and design dimensions of the condenser plant.

Condensate Depression

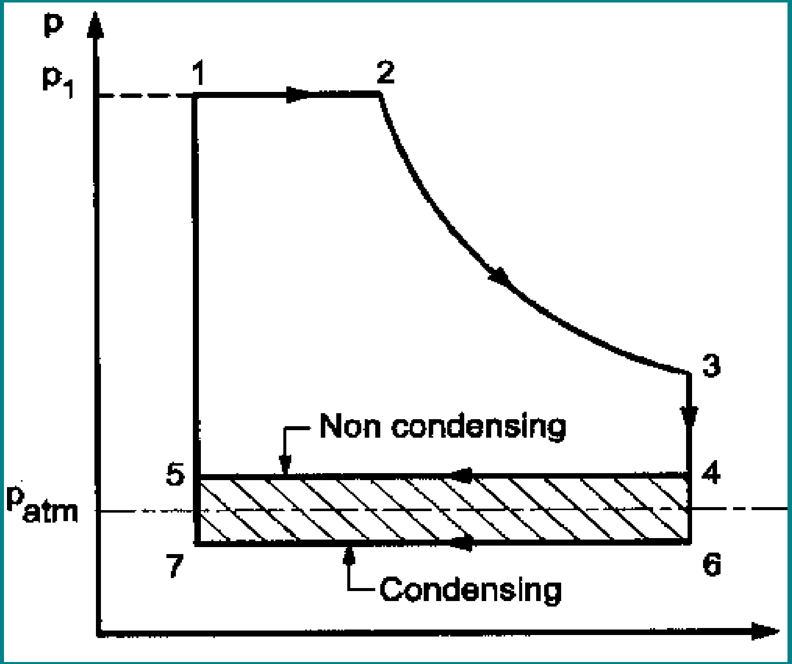
- The temperature of condensate is always a few degrees lower than the coincident condensing steam temperature.
- Subcooling of condensate is undesirable on two accouts:
- It lowers the thermodynamic efficiency of the power cycle.
- It enhances the propensity of the condensate to reabsorb non-condensibles.

PRINCIPLE OF CONDENSATION



- In order to attain maximum work, according to Carnot principle, the heat must be supplied at Maximum pressure and temperature and should be rejected at Minimum pressure and temperature.

PRINCIPLE OF CONDENSATION

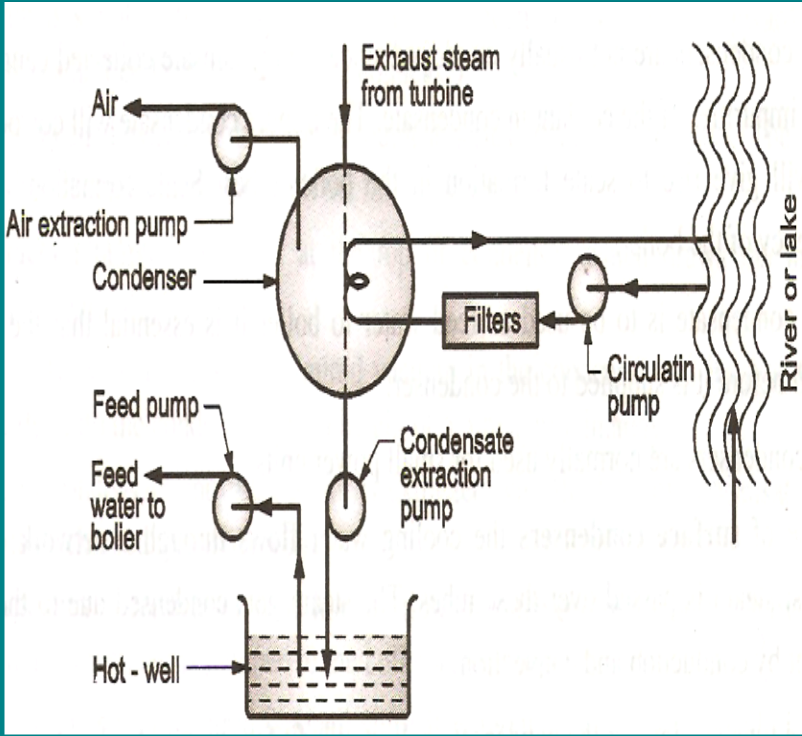


- The steam from the steam turbine or steam engine could be exhausted to atmosphere in such a manner that the back pressure would below the atmospheric pressure.

CONDENSER ADVANTAGES

- It increases the work output per kg of steam supplied to the power plant.
- Reduces the specific steam consumption.
- Reduces the size of power plant of given capacity.
- Improves the thermal efficiency of power plant.
- Saves the cost of water to be supplied to boiler.

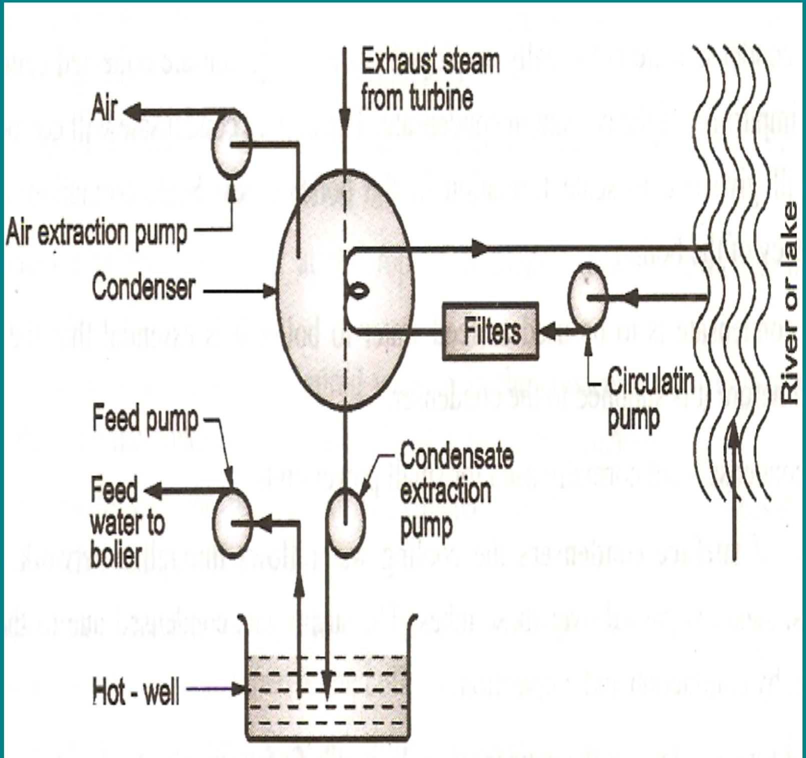
CONDENSER ELEMENTS



- **CONDENSER**: In which the exhaust steam of the turbine is condensed by circulating cooling water.

- **CONDENSATE EXTRACTION PUMP:** to remove the condensate from the condenser and feed it into the hot-well. The feed water from hot-well is further pumped to boiler.

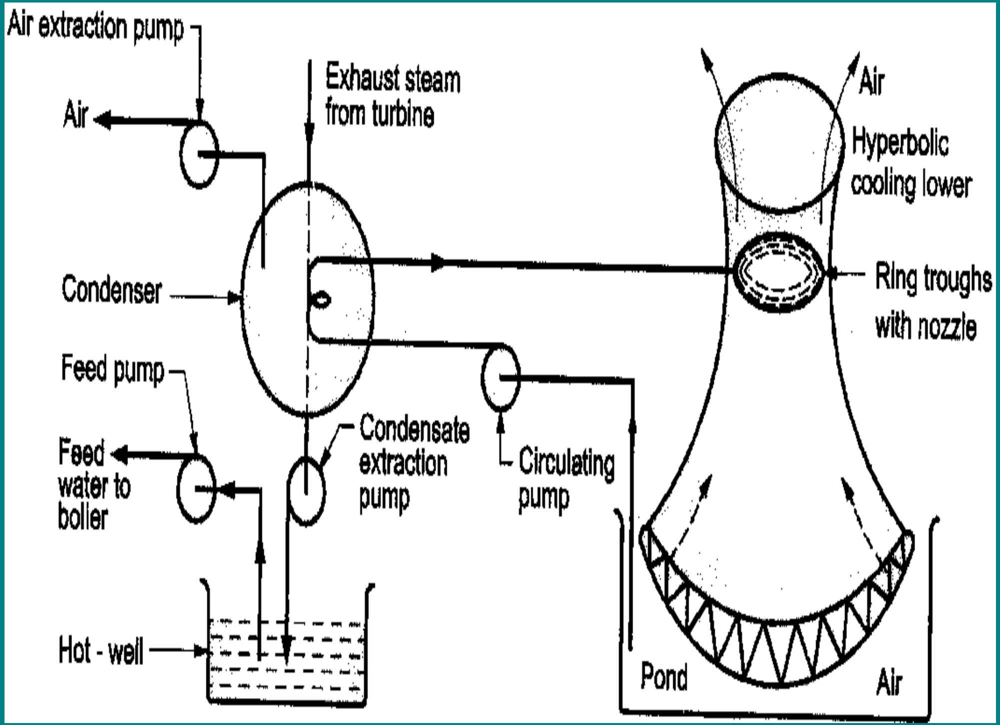
CONDENSER ELEMENTS



- **AIR EXTRACTION PUMP**: to remove air from the condenser, such a pump is called dry air pump. If air and condensate both are removed, it is called as wet air pump.

- **CIRCULATING PUMP**: used to supply feed water either from river or from the cooling tower pond to the condenser.

CONDENSER ELEMENTS



- **COOLING TOWER:**

1. The Ferro concrete made device (hyperbolic shape) in which the hot water from the condenser is cooled by rejecting heat to current of air passing in the counter direction.
2. Ring troughs are placed 8-10m above the ground level.

CONDENSER TYPES

- **JET CONDENSERS**

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

- **SURFACE CONDENSERS**

  The cooling water flows through a network 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.

JET CONDENSERS

CLASSIFICATION OF JET CONDENSERS

1. Low level jet condensers

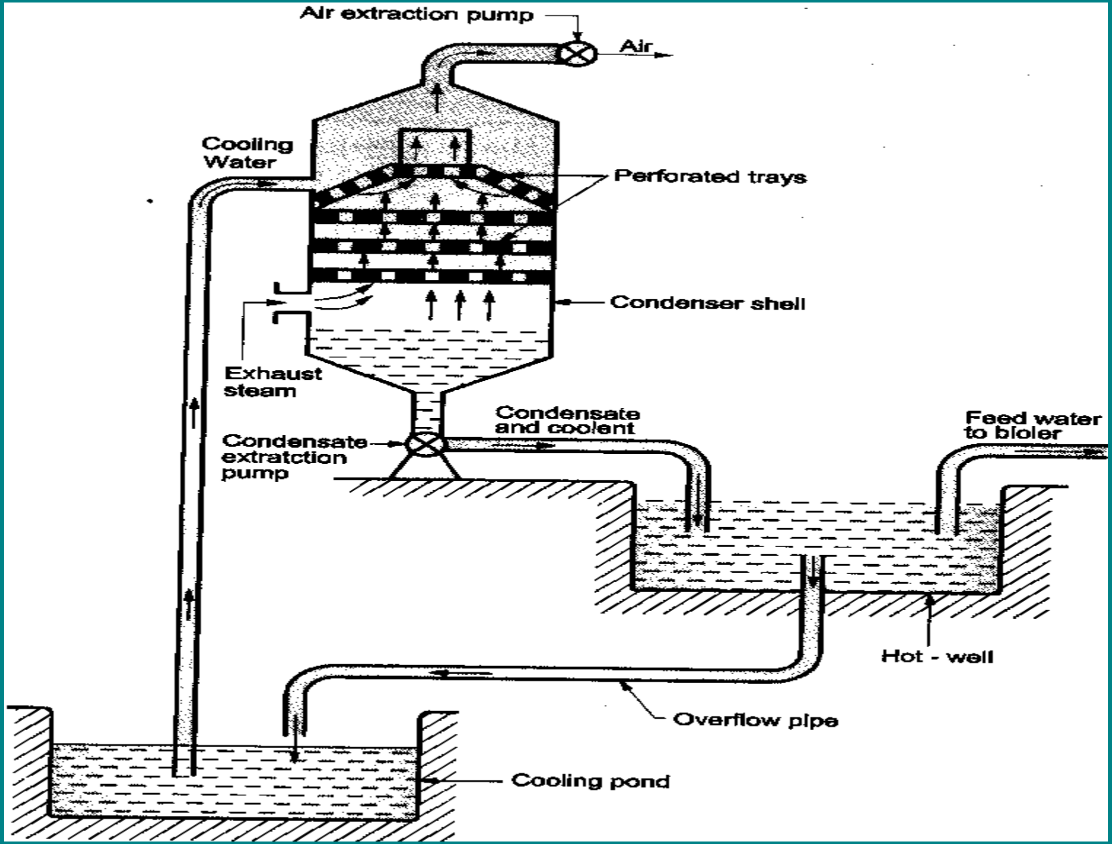
i) *Counter flow type*

ii) *Parallel flow type*

2. High level jet injectors

3. Ejector jet condensers

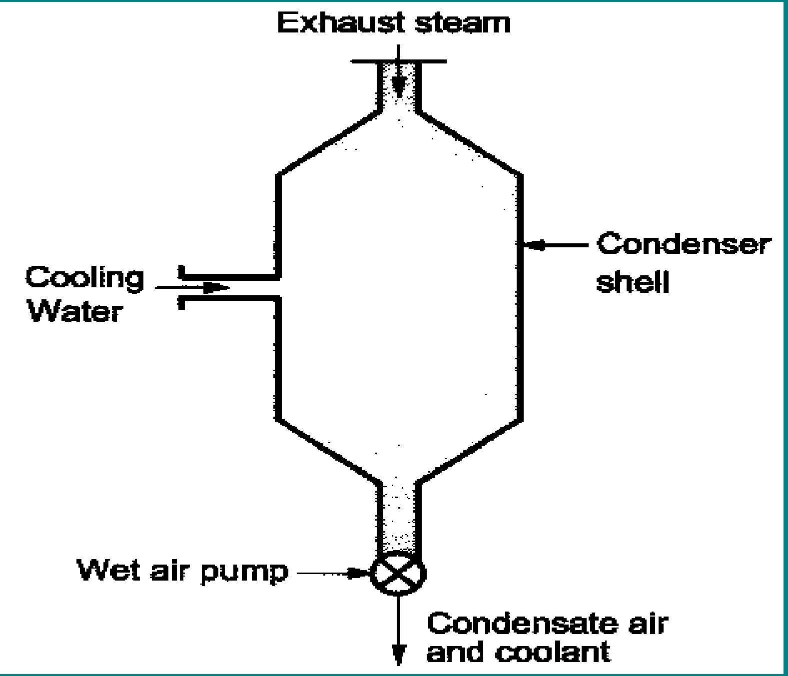
LOW LEVEL COUNTER FLOW JET INJECTOR



- The cooling water to be lifted into the condenser up to a height of 5.5m.

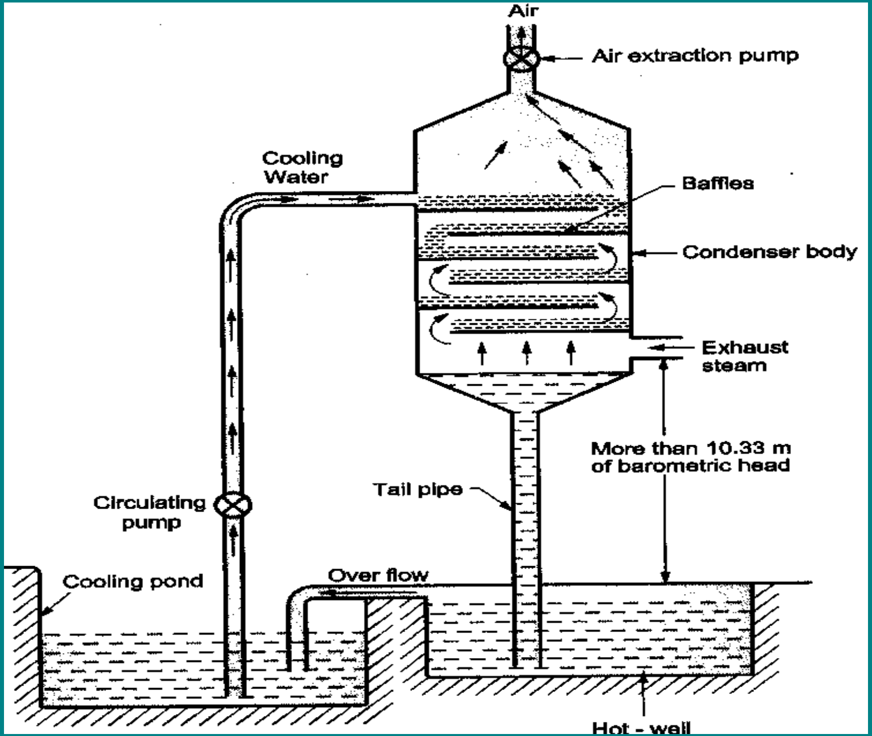
- It is having disadvantage of flooding the steam turbine if the condensate extraction pump fails.

LOW LEVEL PARALLEL FLOW JET INJECTOR



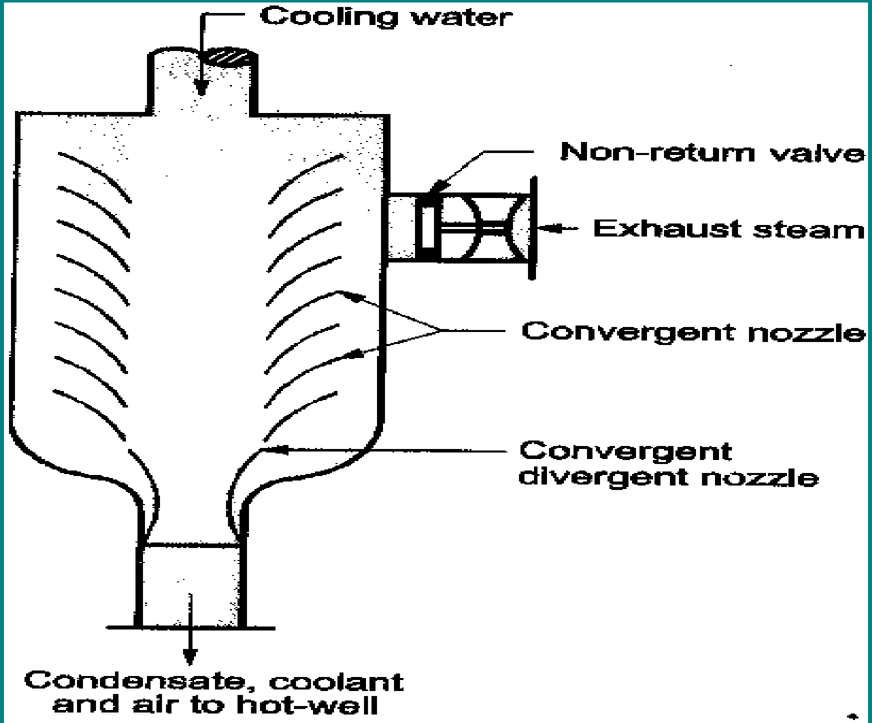
- The mixture of condensate, coolant and air are extracted with the help of wet air pump.
- Vacuum created in the condenser limits up to 600 mm of Hg.

HIGH LEVEL JET CONEDNSER/BAROMETRIC JET CONDENSER



- It is also called Barometric jet condenser since it is placed above the atmospheric pressure equivalent to 10.33 m of water pressure.
- Condensate extraction pump is not required because tail pipe has incorporated in place of it.

EJECTOR JET CONDENSER



- The cooling water enters the top of the condenser at least under a head of 6m of water pressure with the help of centrifugal pump.
- This system is simple, reliable and cheap.
- Disadvantage of mixing of condensate with the coolant.

SURFACE CONDENSERS

Surface condensers are of two types

- **SURFACE CONDENSERS**

  In this steam flows outside the network 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.

CLASSIFICATION OF SURFACE CONDENSERS

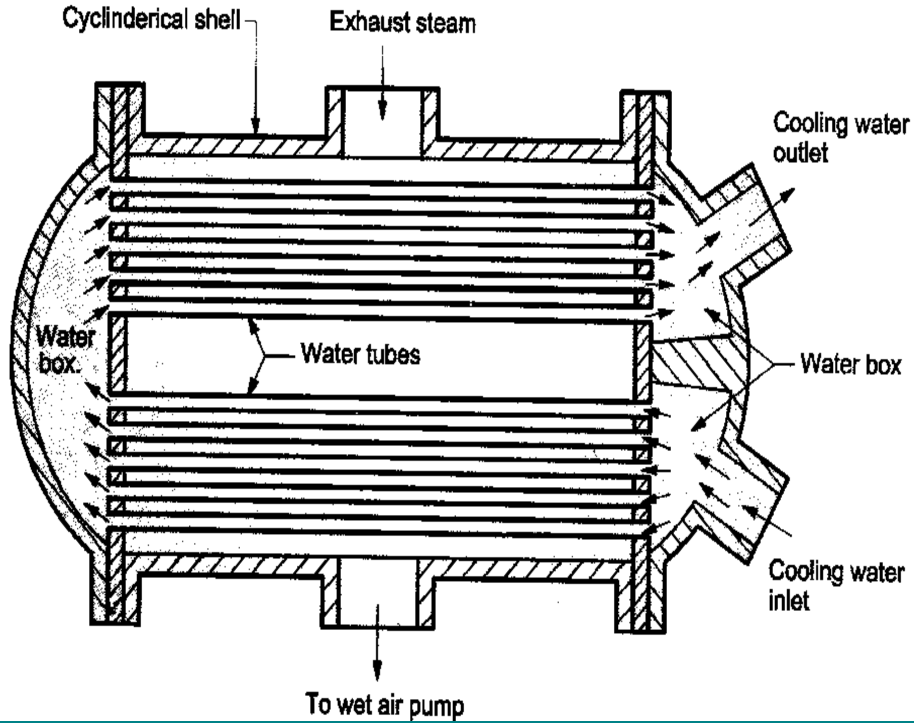
- The number of water passes:

1. Single pass
2. Multipass

- The direction of condensate flow and tube arrangement:

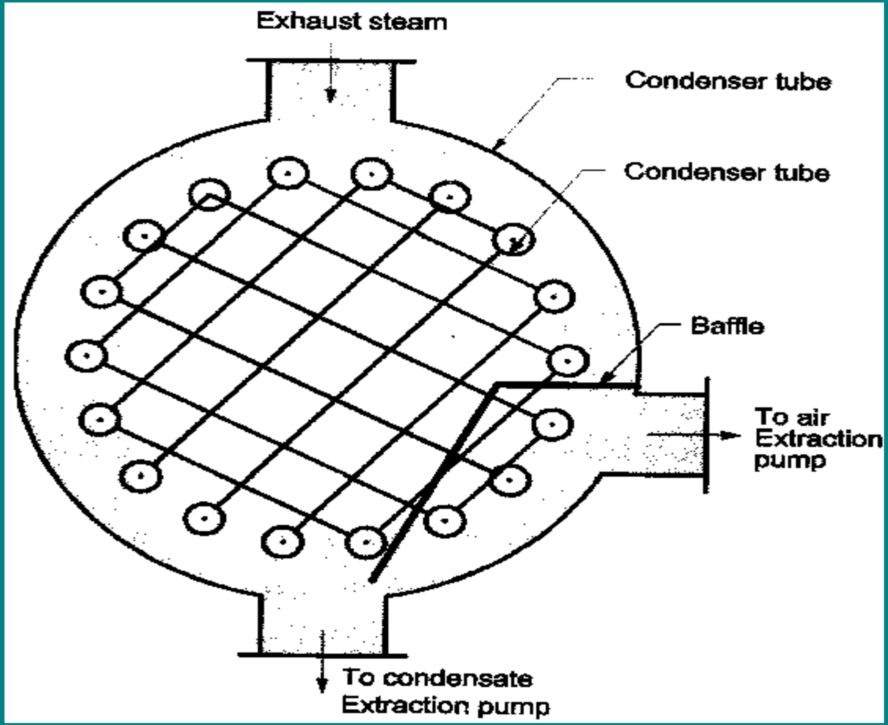
1. Down flow condenser
2. Central flow condenser

DOUBLE PASS SURFACE CONDENSER



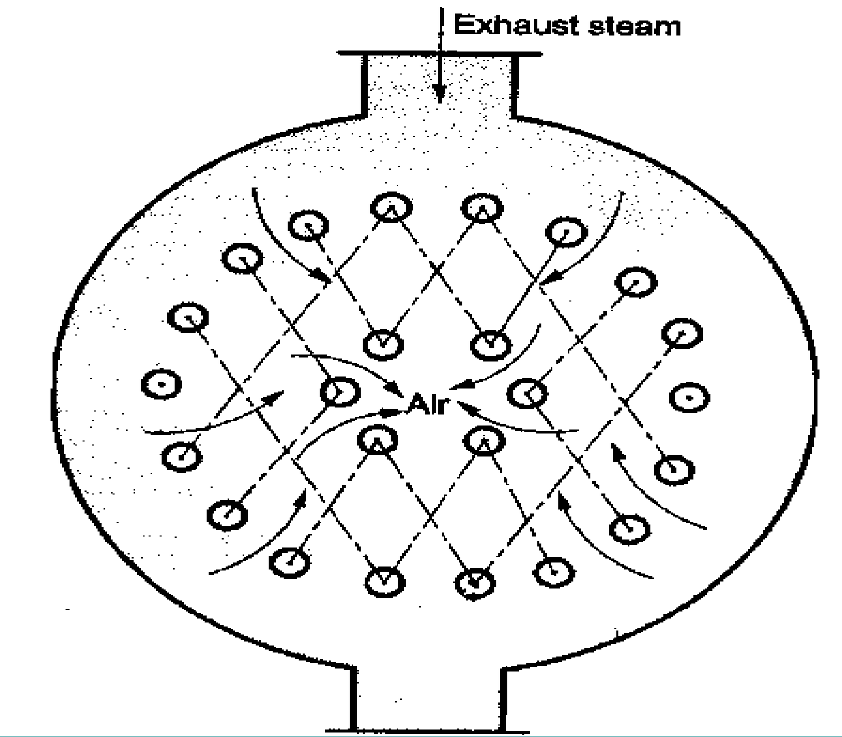
- It consist of air tight cast iron cylindrical shell.
- If cooling water is impure, condenser tubes are made up of red brass.

DOWN FLOW SURFACE CONDENSER



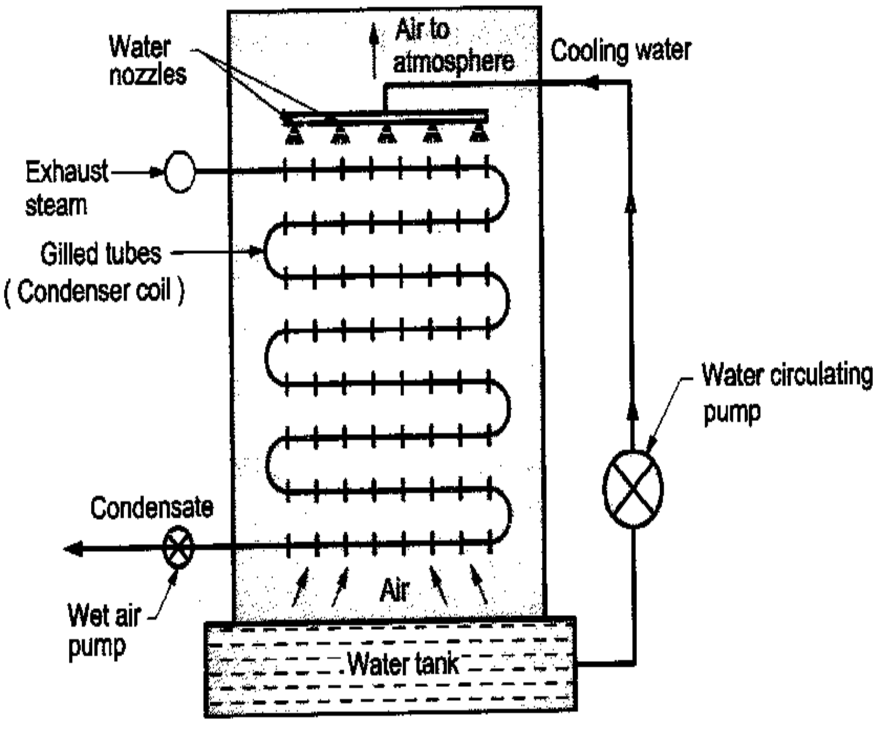
- This condenser employs two separate pumps for the extraction of condensate and the air.
- Baffles are provided so that the air is cooled to the minimum temperature before it is extracted.
- The specific volume of cooled air reduces, thereby, reduces the pump capacity to about 50%. Therefore, it also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

CENTRAL FLOW SURFACE CONDENSER



- Air extraction pump is located at the centre 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.

EVAPORATIVE CONDENSER



- The exhaust steam is passed through the series of gilled tubes called condenser coils.
- Thin film of cooling water trickles over these tubes continuously from water nozzles.
- During the condensation of steam, this thin film of water is evaporated and the remainder water is collected in the water tank.
- The condensate is extracted with the help of wet air pump.
- The air passing over the tubes carries the evaporated water in the form of vapour and it is removed with the help of induced draft fan installed at the top.

MERITS AND DEMERITS OF JET CONDENSERS

MERITS

1. Less quantity of cooling water is required to condense the steam.
2. Simple in construction and low in cost.
3. Does not require cooling water pump.
4. Less space is required.
5. Low maintenance cost.

DEMERITS

1. The condensate is a waste.
2. Less suitable for high capacity plants.
3. Large length of pipes required, hence piping cost is high.
4. Loss of vacuum due to leakage of air from long pipings.

MERITS AND DEMERITS OF SURFACE CONDENSERS

MERITS

1. No mixing of cooling water and steam, hence the condensate directly pumped into the boiler.
2. Any kind of feed water can be used.
3. Develops high vacuum, therefore suitable fro large power plants.
4. Require less power to run the air extraction and water extraction pump.
5. System is more efficient.

DEMERITS

1. Require large quantity of cooling water.
2. System is complicated, costly and requires high maintenance cost.
3. Require large floor space since it is bulky.

Simple Schematic of Geothermal Power Plant

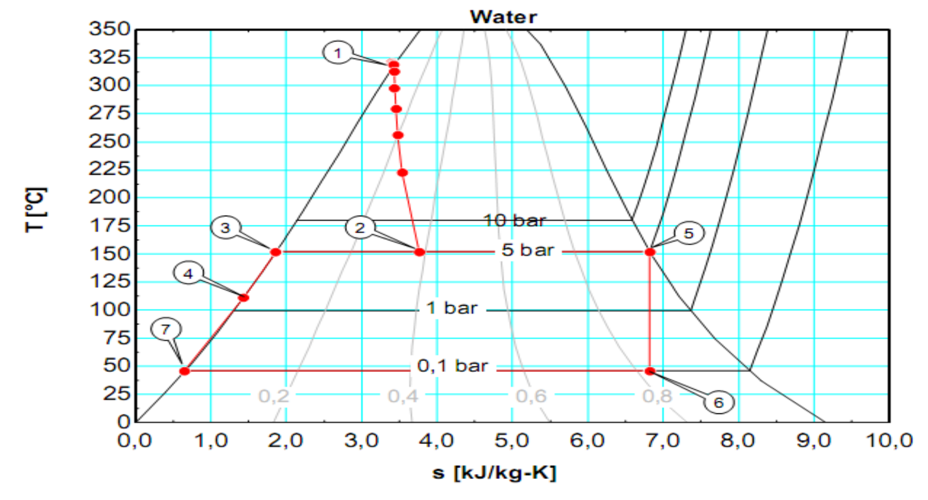
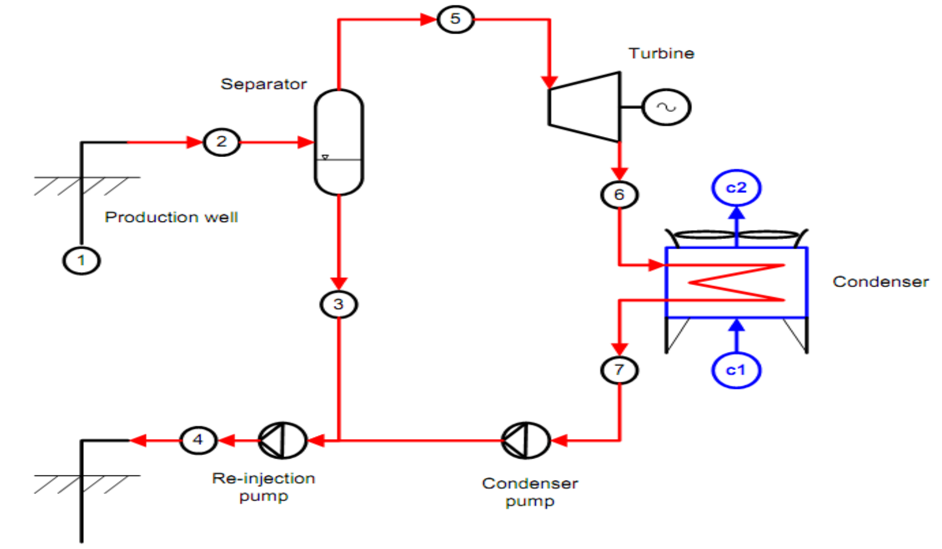


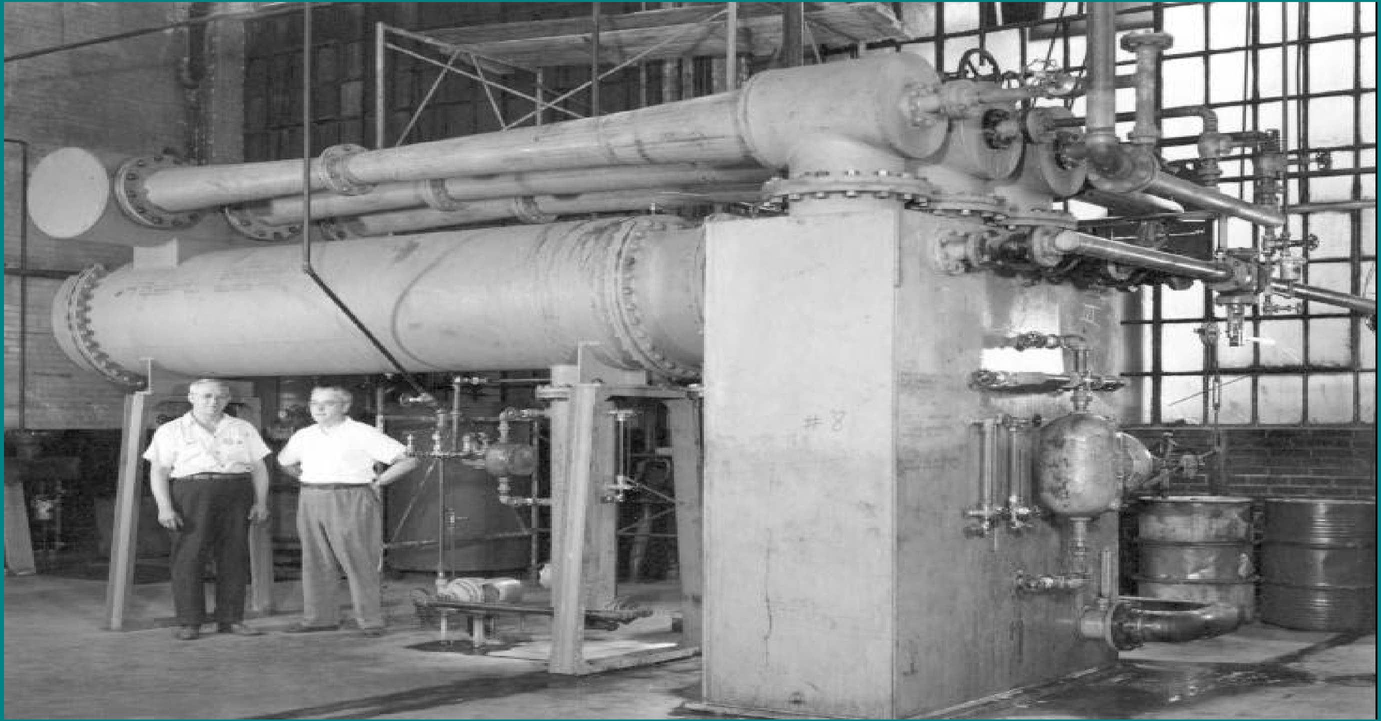
FIGURE 2: T-s diagram of a single flash cycle



Producing Vacuum

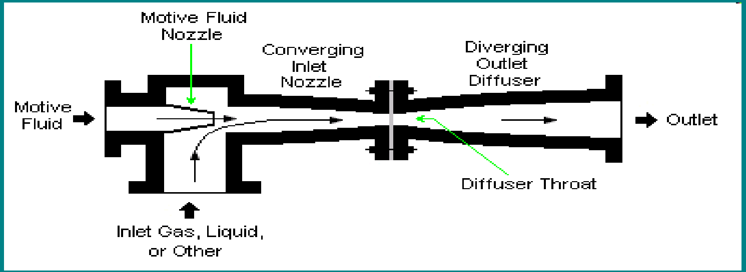
- Types
  - Ejector - advantage = large volumetric flow rate
    - Multi-Stage with interstage condensers
  - Liquid (Oil) Ring Vacuum Pump
  - Dry Vacuum Pump (rotary screw, lobe) (advantage =low pressure) Designs similar to Expanders
- Design for
  - Flow Rate at suction plus
  - Air Leakage Rate
    - Function of pressure and Volume of vessel
- Cost
  - Size factor = Flow Rate at suction
  - Motor for pumps

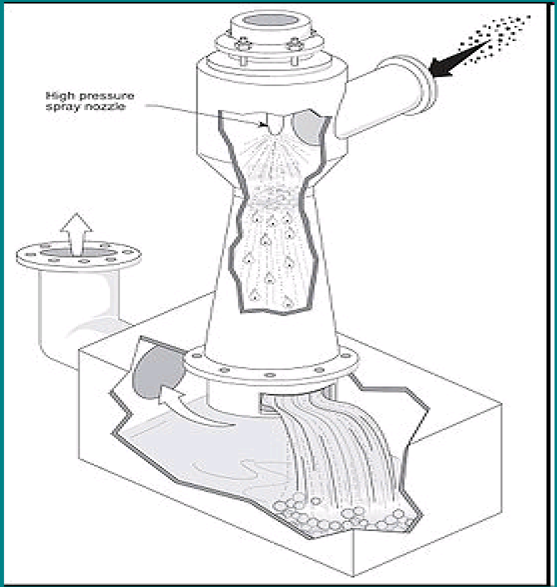
Producing Vacuum Steam Ejector

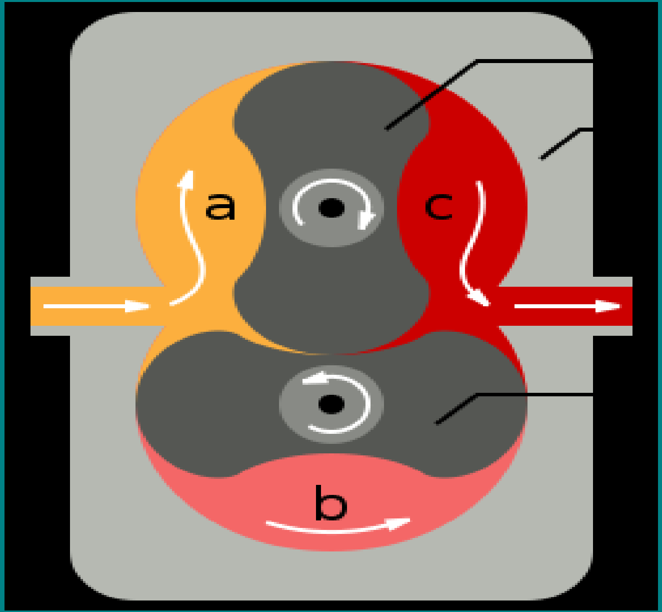


Ejector

- Produces Vacuum
- Provides Low Pressures for Distillation Columns
- Fluid ($P \geq P_{sat}$)
    - Steam
        - for suction pressure below 100 mbar absolute, more than one ejector will be used, with condensors between the ejector stages
    - Air
    - Water
        - Collects Particles in Gas Stream
            - Venturi Scrubber





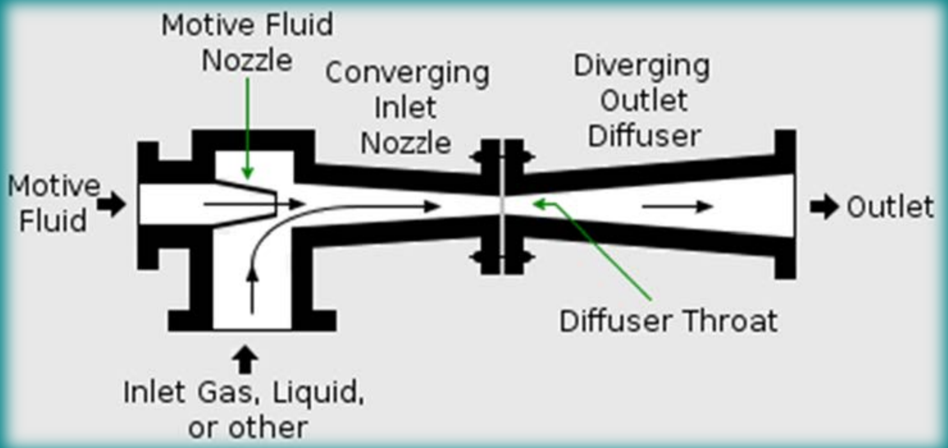


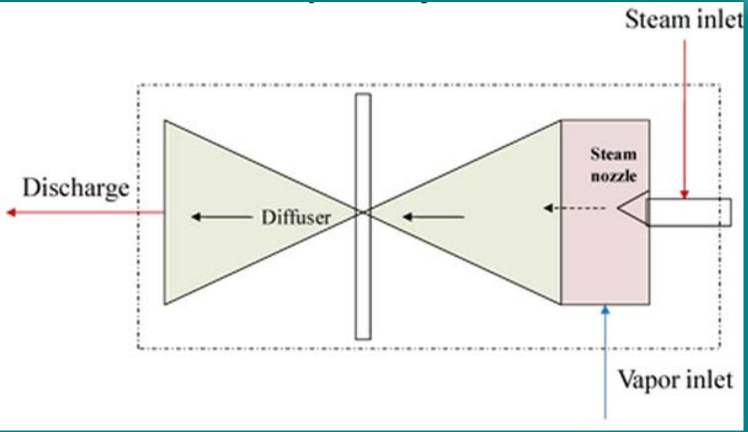
The Roots blower is one example of a vacuum pump

Steam Jet Ejector Vacuum

- Steam Jet Ejector Vacuum components and systems. Based on the ejector-venturi principle, steam issuing through an expanding nozzle has its pressure energy converted to velocity energy.

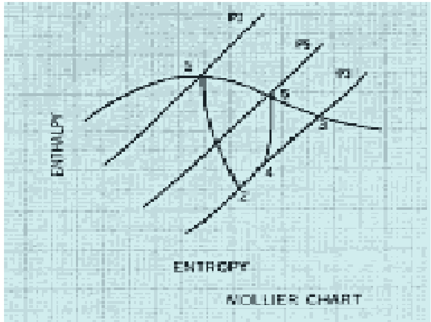
- A vacuum is created, air or gas is entrained and the mixture of gas and steam enters the venturi diffuser where its velocity energy is converted into pressure sufficient to discharge against a predetermined back pressure.





Steam Jet Ejector Vacuum

Ejectors are composed of three basic parts: a nozzle, a mixing chamber and a diffuser. The digram below left illustrates a typical ejector. A high pressure motivating fluid (Ma) and Mb) enters at 1, expands through the converging-diverging nozzle to 2. The suction fluid (Mb) enters at 3, mixes with the motivating fluid in the mixing chamber 4. Both Ma and Mb are then recompressed through the diffuser to 5. The pressure and velocity changes are also shown graphically for the process directly below the ejector diagram. The diagram below right shows the thermal changes on a Mollier diagram for a typical ejector using high pressure steam as the motivating fluid and saturated vapor as the suction fluid.

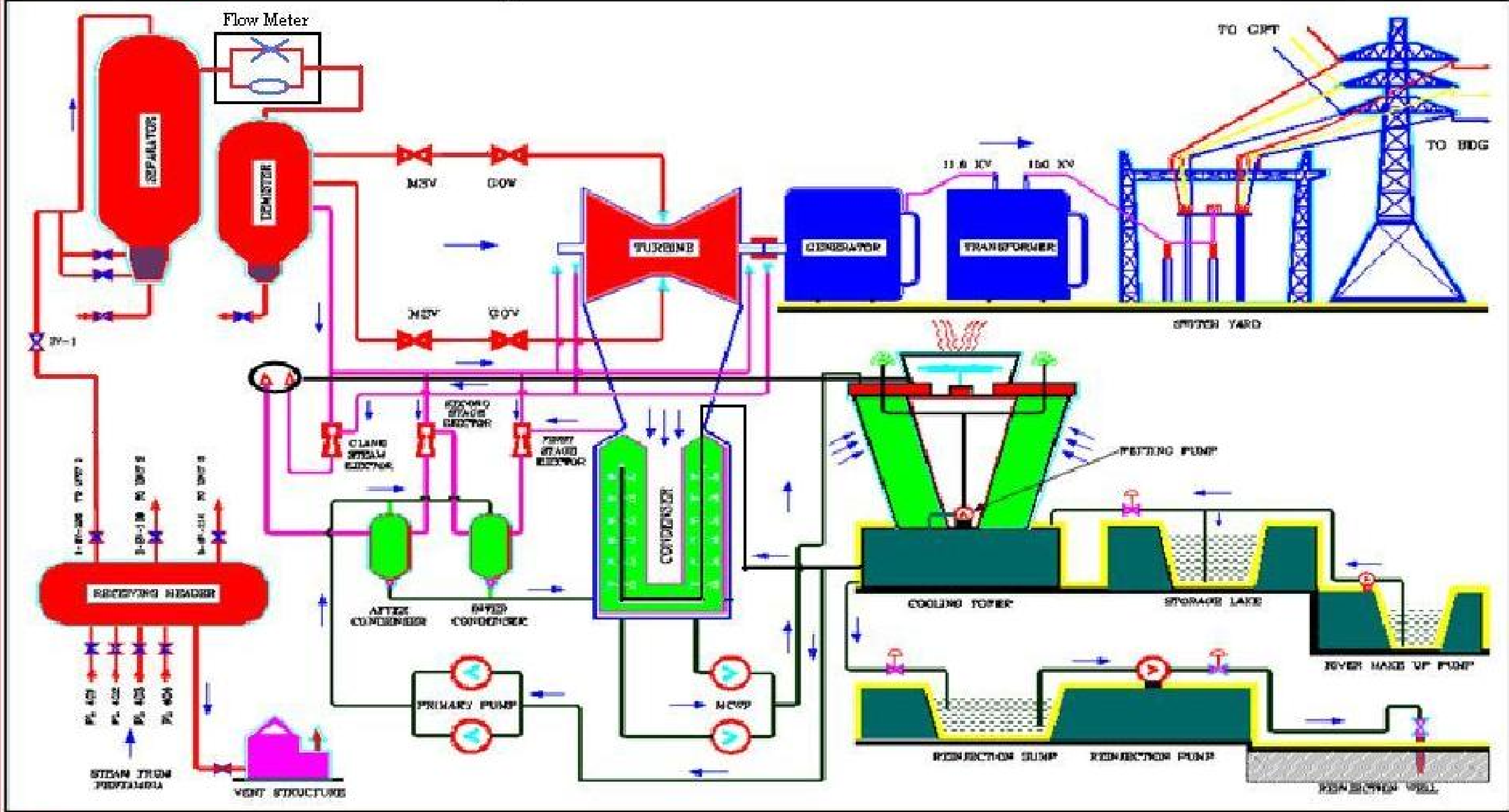


Steam Jet Ejector Vacuum

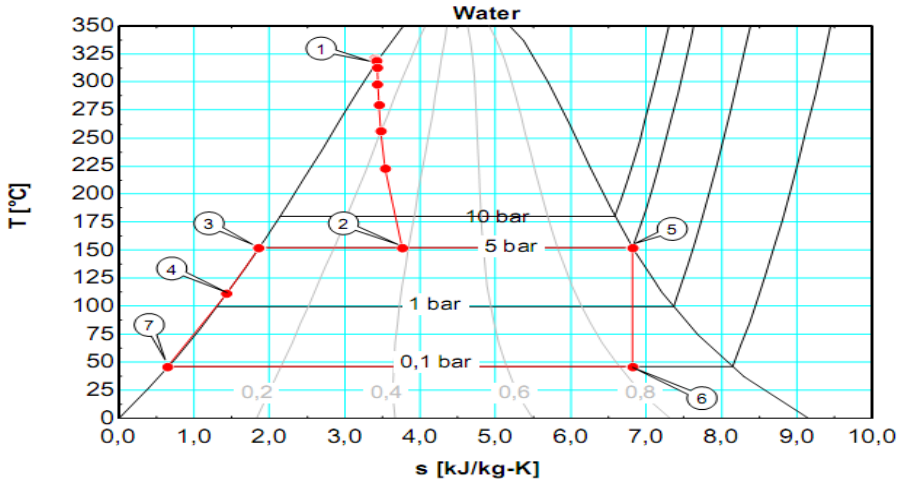
ℵ **Applications**

- Steam jet ejectors are used in the chemical, petrochemical, pulp and paper, food, power, steel and allied industries in connection with such operations as filtration, distillation, absorption, mixing, vacuum packaging, freeze drying, flash cooling, dehydrating and degassing to name just a few.
- They will handle both condensable and non-condensable gases and vapors as well as mixtures of the two. Small amounts of.solids or liquids will not adversely affect p
- erformance. All S&K ejectors are computer designed and type-tested to insure reliability.

FLOW DIAGRAM PLTP KAMOJANG



Simple Schematic of Geothermal Power Plant



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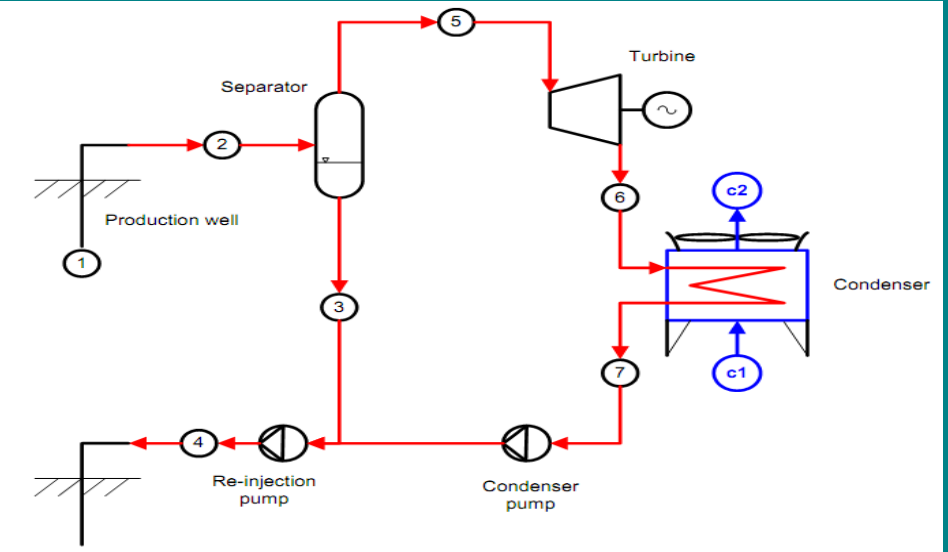
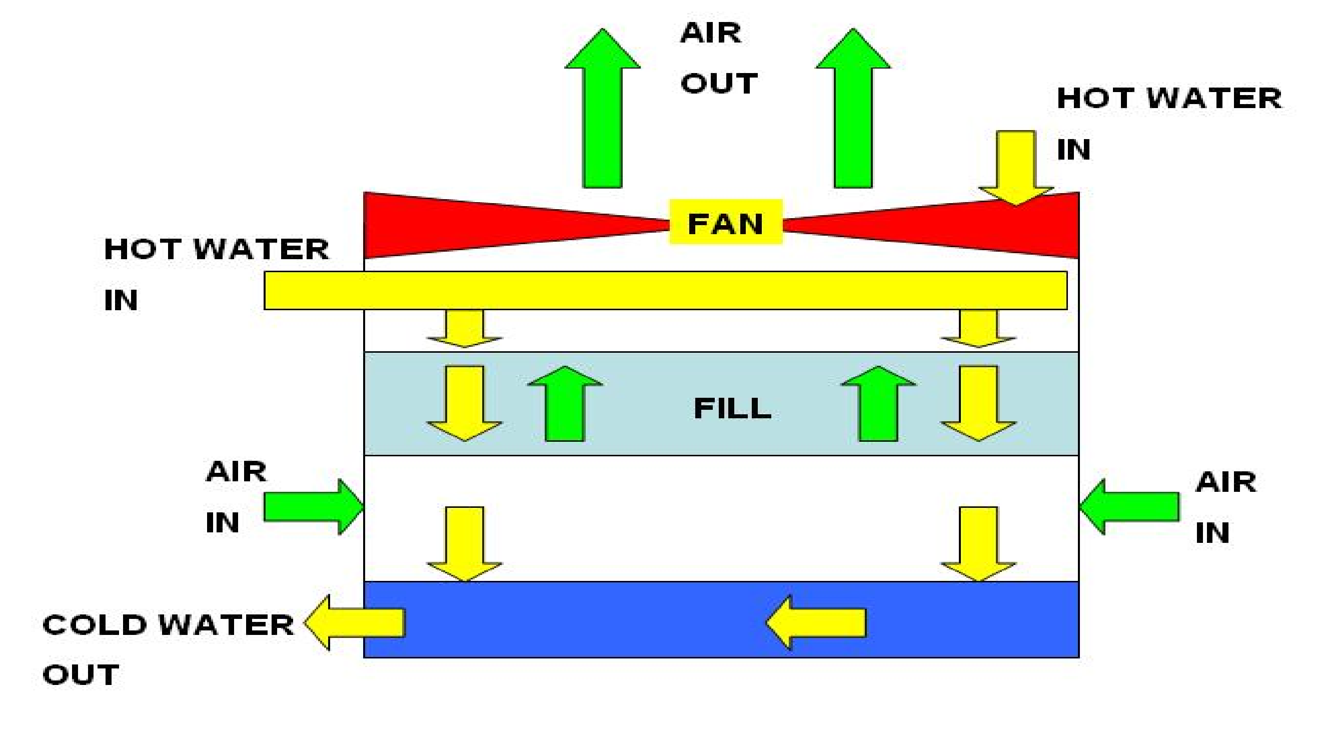


COOLING TOWER

What Does A Cooling Tower Do?

- Cooling Towers are used to transfer heat from cooling water to the atmosphere.
  - Promotes efficient water usage
  - Prevents environmental damage

How Does It Work?



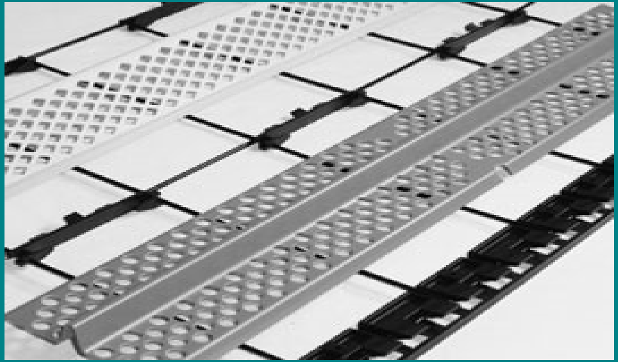
Heat Transfer Methods

- 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.

Heat Transfer Optimization

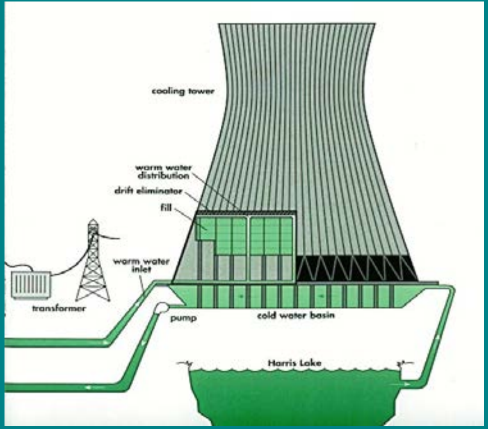
- Heat transfer is proportional to the surface area over which it occurs.
- A Splash fill is used to increase the surface area between the air and water flows.

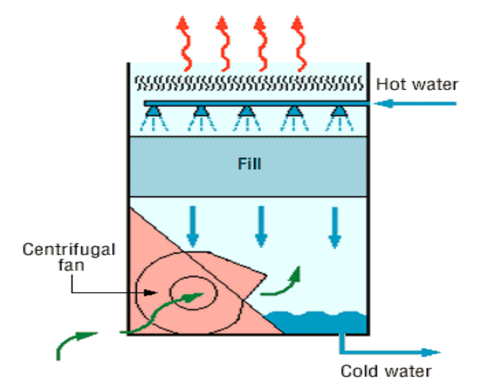


Air Flow Generation Methods

- 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.

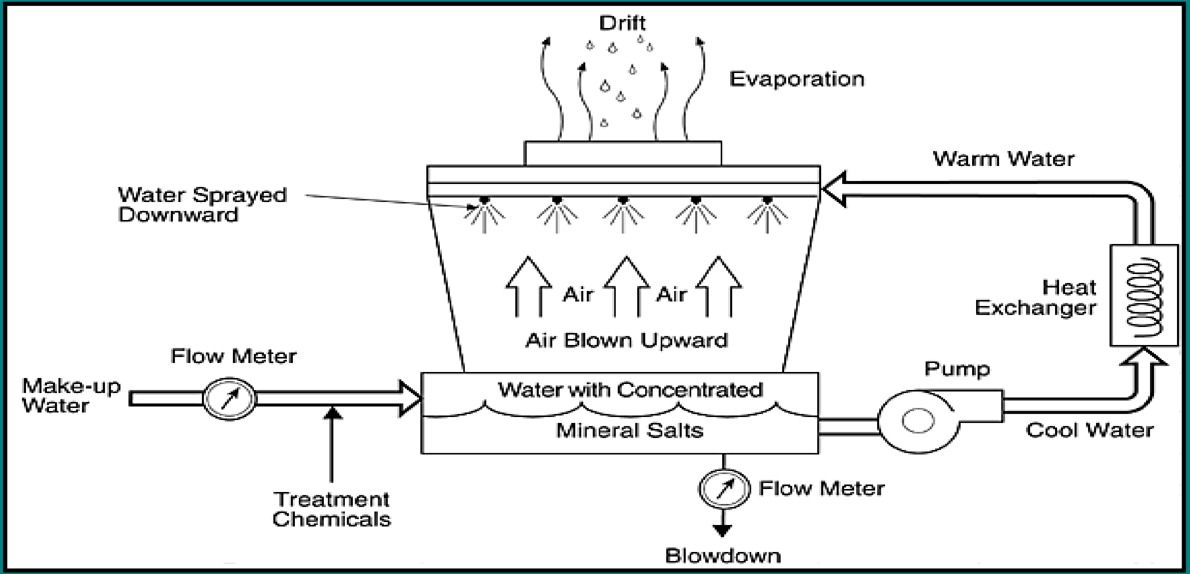




Facts

- The flow rate through a cooling tower in a typical 700 MW power plant is about 315,000 gal/min.
- Cooling towers have 95% efficiency, losing only 5% of circulating water to evaporation.
- Power consumption is minimal due to few moving parts.
- Cooling towers save plants thousands to millions of dollars per year in water consumption and recycling costs.

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 (continue)

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

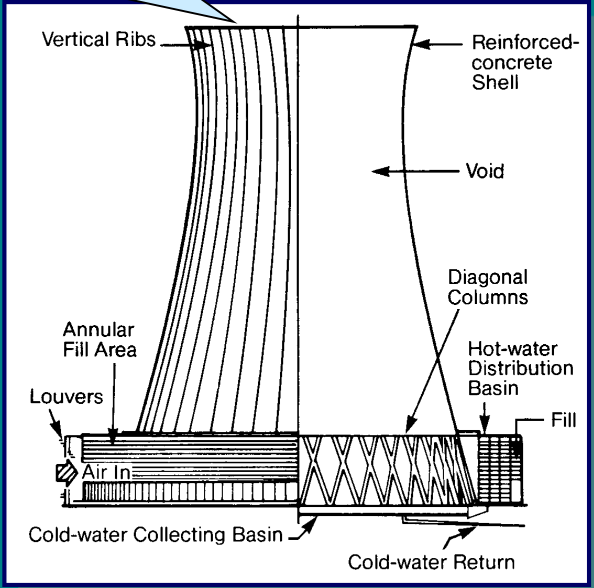
Natural Draft Cooling Towers

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

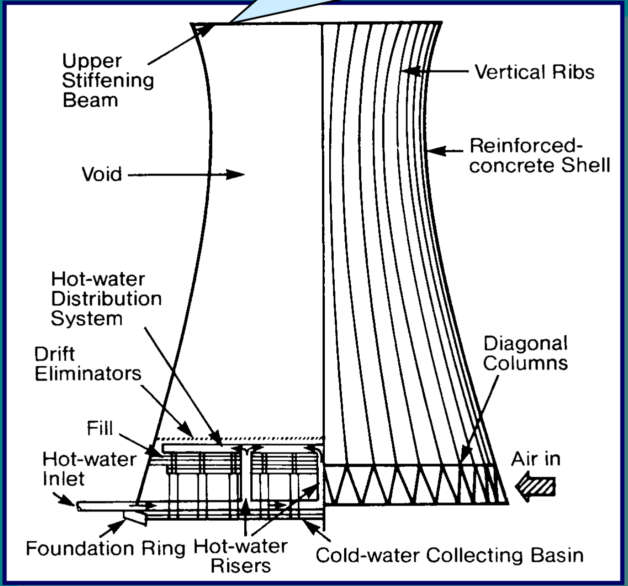
- Air drawn across falling water
- Fill located outside tower

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

Natural Draft Cooling Towers



Cross flow



Counter flow

Cooling Towers

Natural Draught Towers

1. Atmospheric tower

a. General

Air movement through the tower is almost entirely dependent upon natural wind forces. Water falls in a vertical path through a packing while the air moves in a horizontal path, resulting in a cross flow arrangement to achieve a cooling effect. Wind speed is a critical factor in the thermal design and should always be specified. This type of tower is infrequently used in practice.

b. Advantage ⟶ there is no mechanical or electrical maintenance.

c. Disadvantages

- Narrow construction results in considerable length of tower.
- There is high capital cost due to low thermal capacity.
- Unobstructed location broadside on to prevailing wind is required.
- The re-cooled water temperature varies widely with changes in the wind speed and direction.
- The drift loss may be substantial under high wind conditions.

Cooling Towers

2. Hyper-boloidal tower (Commonly known as hyperbolic tower)

a. General

Air flow is affected by the reduction in density of the column of warm saturated air within the tower shell. Secondary effects of wind velocity may influence air flow but are not normally taken into consideration in tower design.

The choice of counter flow, mixed flow or cross flow arrangements is dictated primarily by site and economic considerations.

b. Advantages:

- It is suited to large water flow rates.
- High-level emission of plume virtually eliminates fogging at ground level and recirculation.
- It occupies less ground space than multiple mechanical draught towers for large thermal duty.
- It is independent of wind speed and direction when compared with atmospheric towers.
- There is no fan noise.
- There is no mechanical or electrical maintenance.

c. Disadvantages

- The chimney effect of the shell diminishes ash and this may be a disadvantage in hot dry climate
- Close approach is not economical.
- The considerable height of shell frequently installations presents an amenity disadvantage.

Mechanical Draft Cooling Towers

- Large fans to force air through circulated water
- Water falls over fill surfaces: maximum heat transfer
- Cooling rates depend on many parameters
- Large range of capacities
- Can be grouped, e.g. 8-cell tower

Mechanical Draft Cooling Towers

There are three types:

- Forced draft
- Induced draft cross flow
- Induced draft counter flow

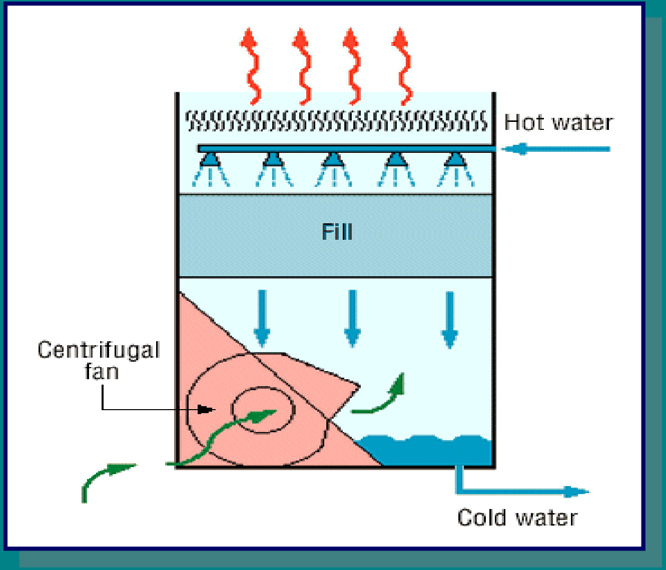
Mechanical Draught Towers

General

Fans are used to produce air movement through the tower. This enables the air flow to be determined independently of other process conditions. Correct quantities and velocities of air may be selected to satisfy various design demands.

Several alternative ways of locating the fans in relation to tower structure are used to obtain specific advantages; also there are two basic flow arrangements for air-water flow, the counter-flow and the cross-flow

Forced Draft Cooling Towers



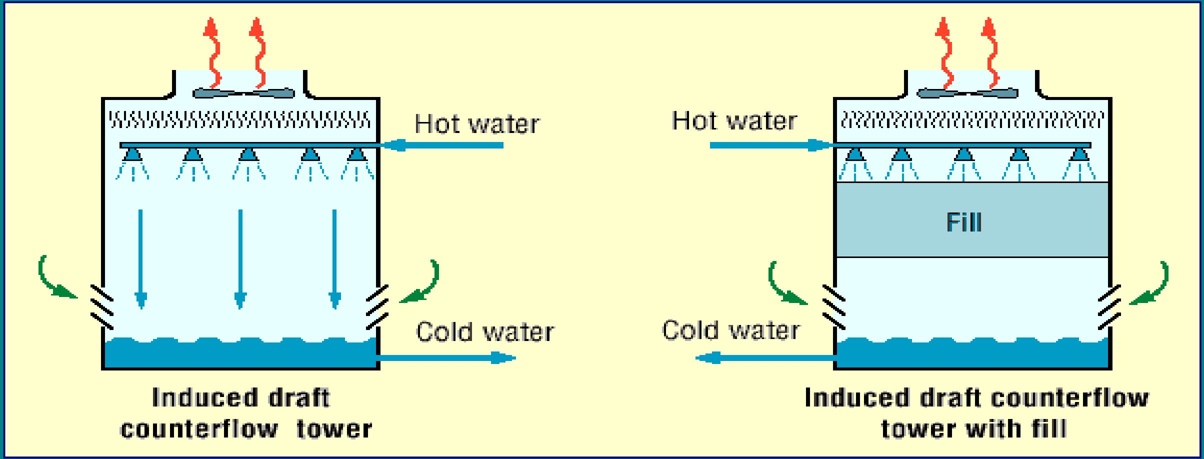
- Air blown through tower by centrifugal fan at air inlet
- Advantages: suited for high air resistance & fans are relatively quiet
- Disadvantages: recirculation due to high air-entry and low air-exit velocities

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

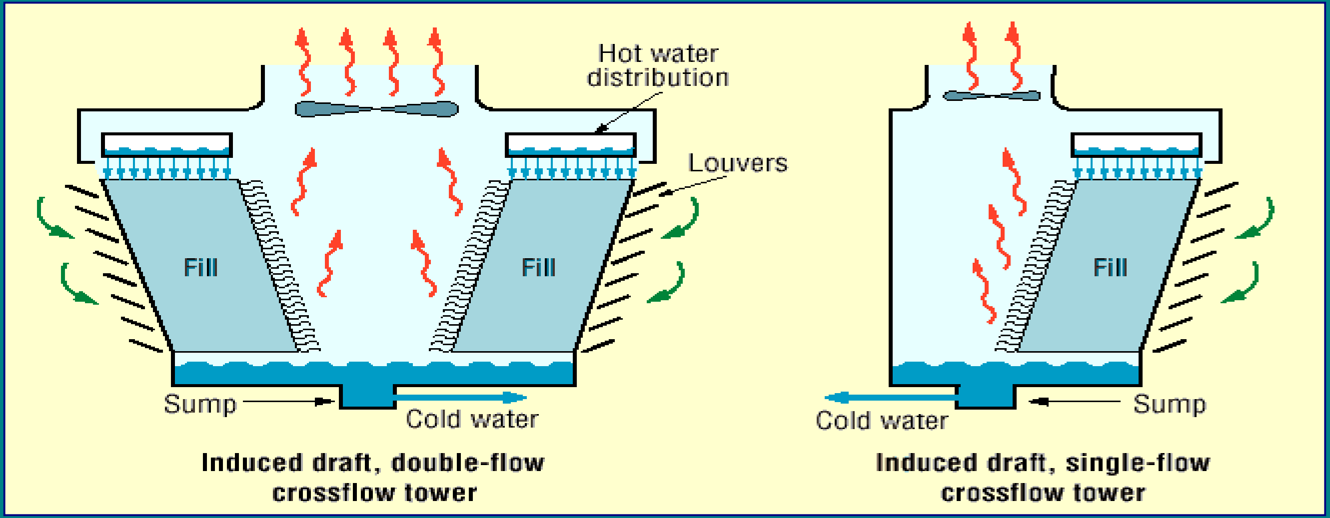
Induced Draft Counter Flow CT

- 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



Measured Parameters in Accessment

- Wet bulb temperature of air
- Dry bulb temperature of air
- Cooling tower inlet water temperature
- Cooling tower outlet water temperature
- Exhaust air temperature
- Electrical readings of pump and fan motors
- Water flow rate
- Air flow rate

Performance Parameters

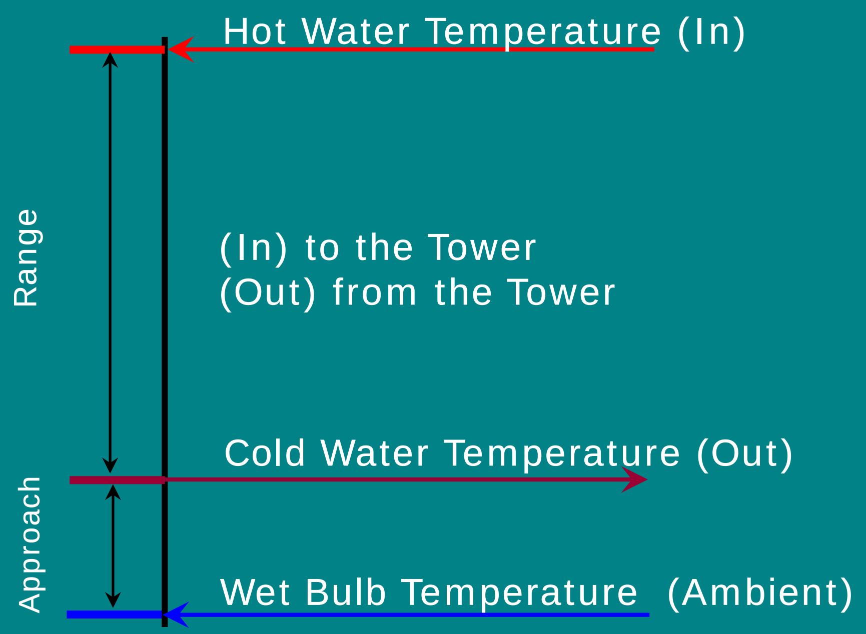
1. Range
2. Approach
3. Effectiveness
4. Cooling capacity
5. Evaporation loss
6. Cycles of concentration
7. Blow down losses
8. Liquid / Gas ratio

RANGE

Difference between cooling water inlet and outlet temperature:

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

High range = good performance

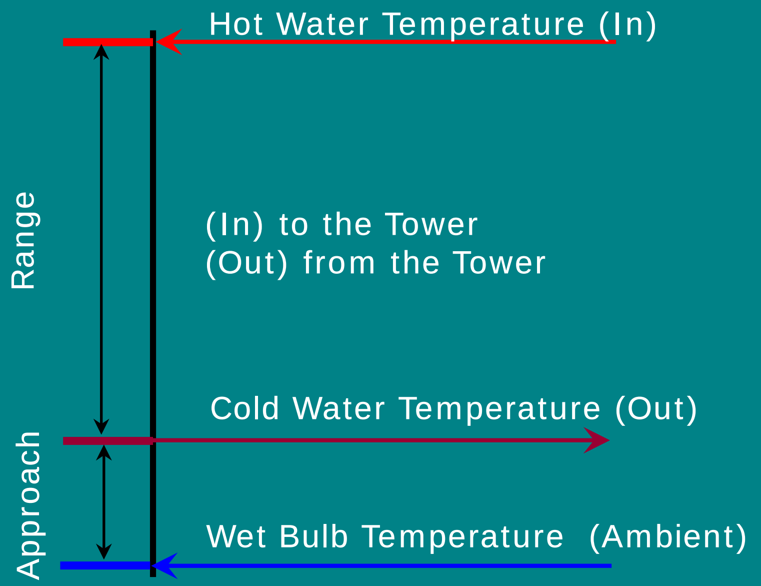


APPROACH

Difference between cooling tower outlet cold water temperature and ambient wet bulb temperature:

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

Low approach = good performance



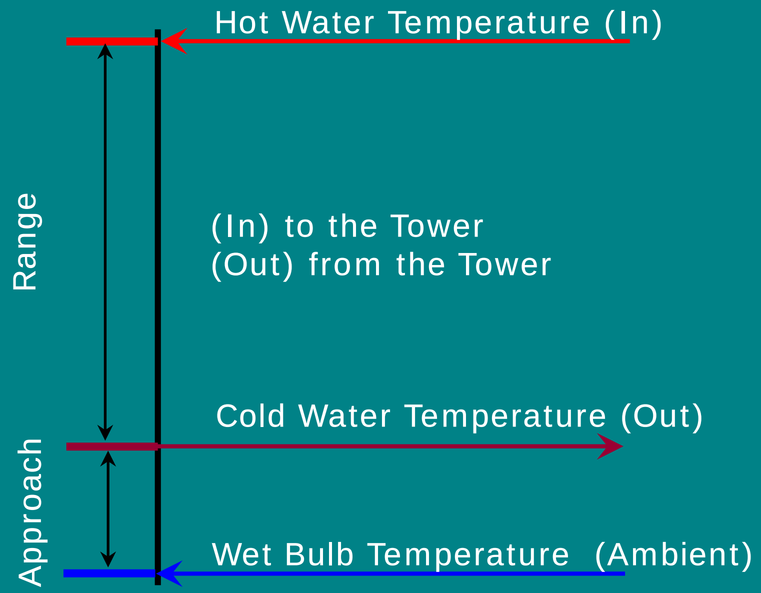
EFFECTIVENESS

Effectiveness in %

= Range / (Range + Approach)

= 100 x (CW temp – CW out temp) / (CW in temp – Wet bulb temp)

High effectiveness = good performance

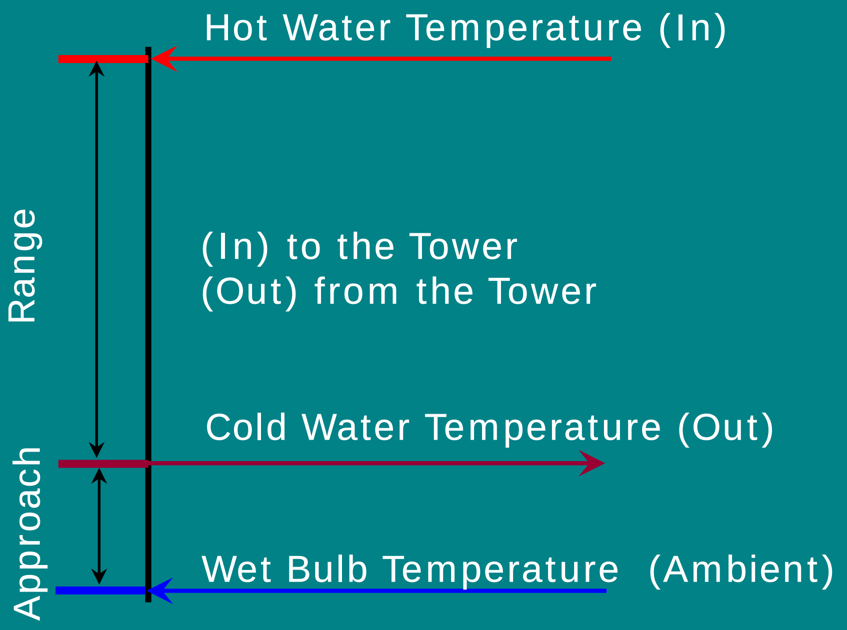


Cooling Capacity

Heat rejected in kCal/hr or tons of refrigeration (TR)

= mass flow rate of water X specific heat X temperature difference

High cooling capacity = good performance



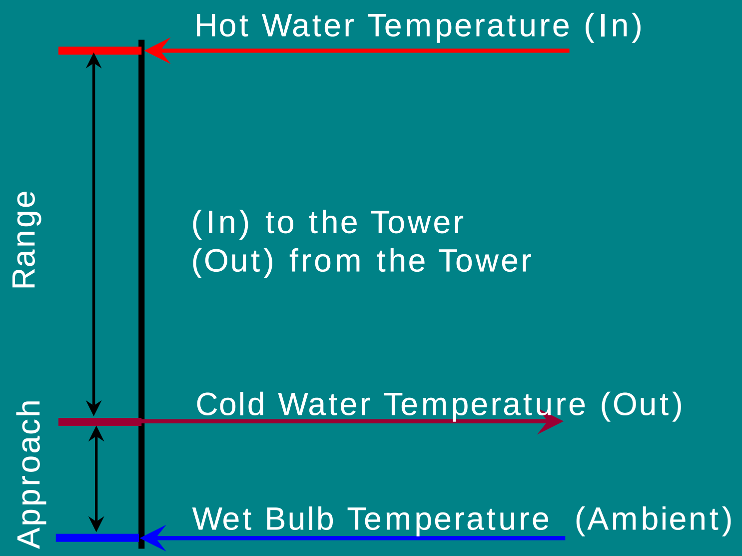
Evaporation Loss

Water quantity (m3/hr) evaporated for cooling duty

= theoretically, 1.8 m3 for every 10,000,000 kCal heat rejected

= 0.00085 x 1.8 x circulation rate (m3/hr) x (T1-T2)

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



Cycles of concentration (C.O.C.)

- Ratio of dissolved solids in circulating water to the dissolved solids in make up water
- Depend on cycles of concentration and the evaporation losses

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

Liquid Gas (L/G) Ratio

- Ratio between water and air mass flow rates
- *Heat removed from the water must be equal to the heat absorbed by the surrounding air*
- $L(T1 - T2) = G(h2 - h1)$
- $L/G = (h2 - h1) / (T1 - T2)$

Where: T1 = hot water temp (^oC)

T2 = cold water temp (^oC)

h1 = enthalpy of air water vapor mixture at inlet wet bulb temp

h2 = enthalpy of air water vapor mixture at outlet wet bulb temp

ENERGY EFFICIENCY OPPORTUNITIES IN COOLING TOWER

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 (m^3/hr)
- Other factors

Selecting a cooling tower

Range

- Range determined by process, <u>not</u> 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

Selecting a 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

Selecting a cooling tower

Relationship Approach and Wet bulb temperature

- If approach stays the same (e.g. 4.45 ºC)
- Higher wet bulb temperature (26.67 ºC)
    - = more heat picked up (15.5 kCal/kg air)
    - = smaller tower needed
- Lower wet bulb temperature (21.11 ºC)
    - = less heat picked up (12.1 kCal/kg air)
    - = larger tower needed

Selecting a cooling tower

Relationship Approach and Wet bulb temperature

- If approach stays the same (e.g. 4.45 ºC)
- Higher wet bulb temperature (26.67 ºC)
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- Lower wet bulb temperature (21.11 ºC)
    - = less heat picked up (12.1 kCal/kg air)
    - = larger tower needed

FILL MEDIA

- Hot water distributed over fill media and cools down through evaporation
- Fill media impacts electricity use
  - Efficiently designed fill media reduces pumping costs
  - Fill media influences heat exchange: surface area, duration of contact, turbulence

FILL MEDIA

Comparing 3 fill media: film fill more efficient

	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 m^2/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**

Pumps and water distribution

- Pumps: see pumps session
- Optimize cooling water treatment
  - Increase cycles of concentration (COC) by cooling water treatment helps reduce make up water
  - Indirect electricity savings
- Install drift eliminators
  - Reduce drift loss from 0.02% to only 0.003 – 0.001%

Cooling Tower Fans

- Fans must overcome system resistance, pressure loss: impacts electricity use
- Fan efficiency depends on blade profile
  - Replace metallic fans with FBR blades (20-30% savings)
  - Use blades with aerodynamic profile (85-92% fan efficiency)

OTHER COMPONENTS AND PROCESS

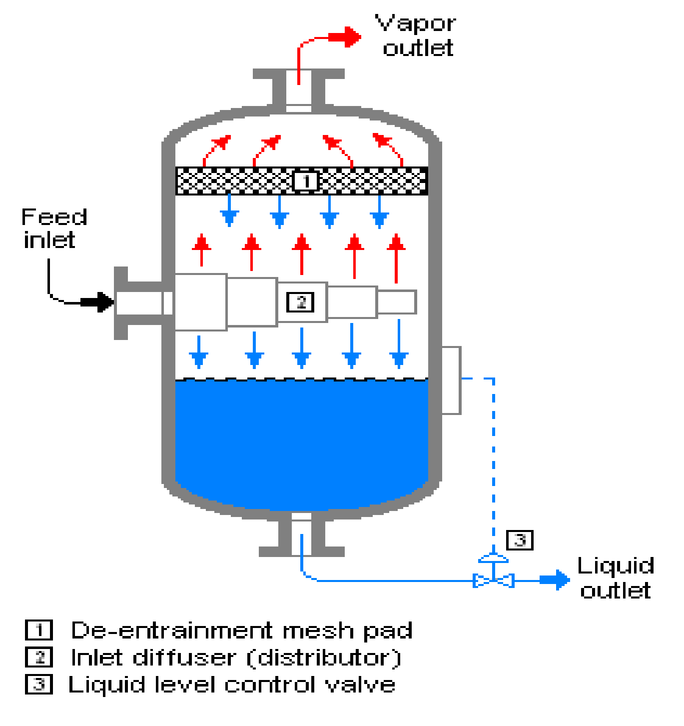
Separator

Separators – separate the steam and liquid phases with small inherent pressure drop

- Use cyclone separator principle
- 2nd flash separators typically designed on same principle, throttle brine to lower pressure to flash proportion to steam prior to separation

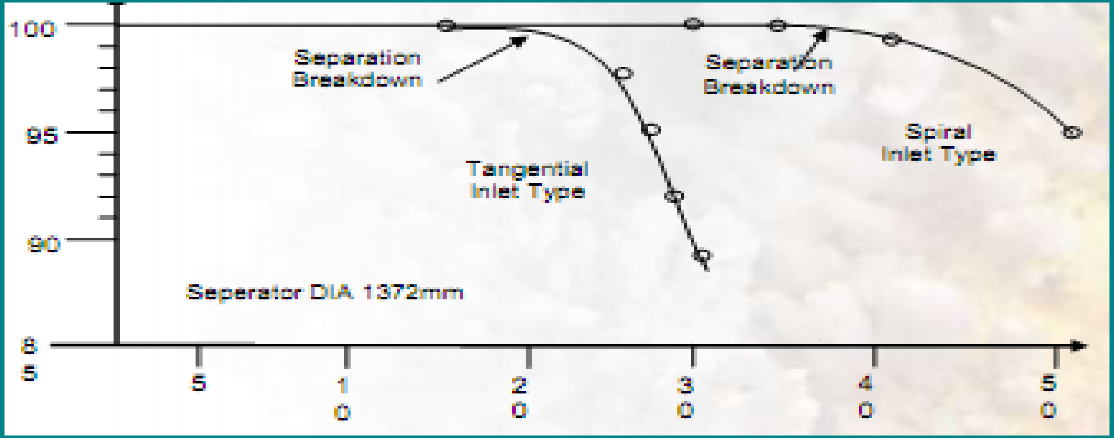
Separator Principle

- Settling and sedimentation
- Inertial and centrifugal separation
- Electrostatic precipitation
- Filtration
- Scrubbing
- Flotation
- Drying



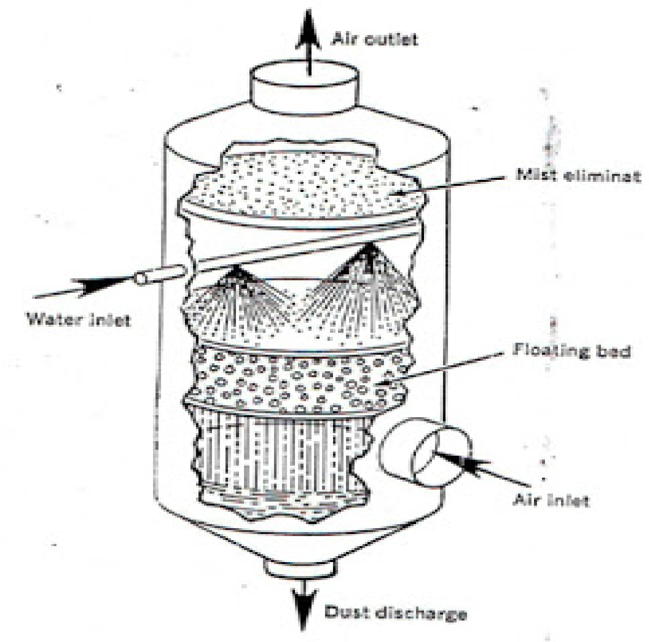
Separator Principle

- Solids and easily dissolved impurities follow the liquid phase. NCG's and volatiles follow the steam phase
- High separation efficiency minimises impurities in the steam



Steam Scrubber

- Drop pots, scrubbers and demisters remove impurities in the condensate
- Geothermal steam deposits are quite corrosive, important to keep air out, minimise shutdowns
- Pipeline steam scrubbing – condensation nucleates on impurities
- Steam washing – inject de-oxygenated water to promote condensation



Gas Extraction Systems

Multi-stage compression used to allow use of inter stage cooling to minimize size and steam/power use

- Multiple trains can be used for flexibility to allow matching of gas extraction system capacity to actual steam NCG content – eg. 40%, 60%, 80% trains
- Choice of mechanical compressors, steam ejectors or hybrid steam ejectors and liquid ring vacuum pumps (LRVPs)
- Optimum choice depends on NCG content of steam, roughly >5-6% implies mechanical compression, 2-6% hybrid ejectors+LRVP, <2% 2 or 3 stage steam ejectors
- Considerable overlap depending on detailed optimisation

Gas extraction systems

Steam ejectors

- lower cost, reliable but use large amount of steam
- Performance of inter-condensers critical to good performance. Check inter-stage gas temperatures are close to design to verify

Hybrid steam ejectors + LRVPs

- 1 or 2 stages has to cope with high volumetric flow, so use steam ejectors
- Final stage LRVPs, slow speed, reliable, reasonably efficient