UNIT-II A

Unit 2: Steam Condenser and Environmental Impacts of Thermal Power Plant

A) Steam Condenser: Necessity of steam condenser, elements of steam condensing plant, classification, cooling water requirements, condenser efficiency, vacuum efficiency (Numerical Treatment), cooling towers, air leakage and its effects on condenser performance, air pumps (Numerical Treatment for Air Pump capacity)
Steam Condenser

- **Steam** condenser is a device in which the exhaust steam from steam turbine is condensed by means of cooling water.

- The main purpose of a **steam condenser in turbine** is to maintain a low back pressure on the exhaust side of the steam turbine.

- After releasing from nozzles, the steam has to expand to a great extent for converting available energy into it to usable mechanical work. So, if the steam after doing its work, does not get condensed, it will not give required space to other steam behind it, to expand to its required volume.
• Condensation of steam in a closed system, creates an empty place by reduction of volume of the low pressure steam.

• It is found that, 1 Kg of dry steam at 1.033 kg / cm$^2$ absolute pressure has a volume of 1.673 m$^3$ when it is condensed into water at 100°C in a steam condenser, its volume becomes 0.001044 m$^3$.

• The volume of steam would be thus 1/1644 parts of the space inside the vessel, and the pressure would fall to 0.2 kg / cm$^2$ absolute pressure. This means, pressure in the exhaust of the turbine falls to 0.2 kg / cm$^2$ from 1.033 kg / cm$^2$. 
• A closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure is known as a **condenser**.

**Necessity of condenser**

• The use of the condenser in power plant improves the efficiency by decreasing the exhaust pressure of the steam below atm.

• Steam condensed may be recovered to provide a source of good pure feed water to the boiler & reduces water softening plant capacity considerably.

• Temp $T_2$ is reduced hence Efficiency can be increased.

  \[
  \text{Efficiency} = \left(\frac{T_1 - T_2}{T_1}\right)
  \]
Elements of Steam Condenser

• A steam condensing plant or simply steam condenser consists of
• **Condenser** – where steam gets condensed.
• **Supply of Cooling water** – which provides cold water to condense steam by heat exchanging.
• **Condenser cooling water pump**-
• **Condensate extraction pump**-
• Hot well in which the condensed steam is collected and from it **steam boiler** feed water may be taken if required.
• **Boiler feed pump**
• **Air extraction pump**
  **Wet Air pumps** – They collect condensed steam, the air and un-condensed water vapour and gases from condenser.
  **Dry air pump**
• **Cooling tower**
• **Make up water pump**
Advantages

• The condensed steam is used as feed water for boiler. Thus reduces the cost.
• Efficiency increases as enthalpy drop increases by increasing the vacuum in it.
• The deposition of the salt in the boiler reduces or prevented.
• It reduces overall cost of the plant by increasing efficiency.
The desirable features of good condenser are:

1. Min quantity of circulating water.
2. Min cooling surface area per kW capacity.
3. Min auxiliary power.
4. Max steam condensed per $m^2$ of surface area.
• **Types of Steam Condenser**

• Open type, Closed type
• In a **steam condenser**, steam is always condensed with help of cooling water, but the techniques are different for different condensers. Depending upon condensation techniques, there are mainly two types of steam condensers. They are mainly

  • **Jet Steam Condenser** or **Mixing type**.
  • **Surface Steam Condenser** or **Non-Mixing type**

• Jet Steam Condenser
• Here cooling water is sprayed on the exhaust steam. This is very fast process of condensing steam. But here cooling water and condensed steam are mixed up which can not be separated.
• This can’t be used for boiler as it contains salts and pollutants.
• Parallel and counter flow condensers.
• **Low level, High level and Ejector condenser**.
Surface Steam Condenser

• Here, cooling water and exhaust steam are separated by a barrier and condensation is done by heat exchanging through this barrier wall.

• Cooling water is passed through numbers of water tubes and exhaust steam passes over the outer surface of the tube. The heat of steam is absorbed by the water inside the tube through the wall of the tube.

• In some cases, steam is passed through an array of steam tubes, cooling water is sprayed over the steam tube and condensed steam comes out from the outlet of the tubes.

• Surface steam condensing is slower process than Jet Steam condensing, but the main advantage of surface steam condensing is that, the condensed steam is not thrown to waste but is returned to steam boiler through feed water system.
Jet Condenser

There are mainly three types of jet condensers.

- Low level condenser.
- High level condenser.
- Ejector condenser.

**Low Level Condenser**

Here condenser chamber is placed at low elevation and overall height of the unit is low enough so that the condenser may be directly placed beneath the steam turbine, pump or pumps are required to extract the cooling water condensate and air from the condenser. Low level jet condensers are of two types-

- Counter Flow
- Parallel Flow Jet Condenser.
Fig. 3.119. Low level jet Condenser (Counter Flow).
Counter Flow Low Level Jet Condenser

In this type of steam condenser, the exhaust steam enters from lower part of condenser chamber and cooling water enters from upper parts of that chamber.

The steam goes up inside the chamber whereas cooling water falls down from top, through steam. The condenser chamber is generally provided with more than one water trays perforated with holes to break up the water in small jets.

The process is very fast. The condensed steam along with cooling water comes down through a vertical pipe to extraction pump. This centrifugal type extraction pump push the water to hot well. If required some of water from the hot well can be taken as steam boiler feed water and rest water flows to cooling pond. Boiler feed water is taken from hot well by means of boiler feed pump whereas, surplus water flows by gravity to the cooling pond.
A small capacity air pump is required at the top of the condensed tank, to extract air and uncondensed vapour. The air pump, required for jet condenser is of small capacity for two main reasons.

1. It has to handle air and vapour alone.
2. It has to handle with small volume of air and vapour since the volume of air and vapour is reduced due to their cooling while rising through the steam of condensing water.

In this type of steam condenser, there is no need of extra pump for lifting cooling water from cooling pond to condenser chamber, as the water lifted itself by vacuum created in the condenser due to condensation of exhaust steam.

Although in some cases a pump is used to push the water to condenser.
• **Parallel Flow Low Level Jet Condenser**

• Basic design of parallel flow low level jet condenser is similar to the counter flow low level jet condenser. In this jet condenser, both cooling water and exhaust steam enter to the condenser chamber from the top.

• Heat exhausting takes place during falling of water through the steam. The cooling water, condensed steam along with wet air are collected from the bottom of the condenser by means of single pump. This pump is known as **wet water pump**.

• There is no need of extra dry air pump at the top of the condenser. As a single pump has to deal with condensate, air and water vapour.

• The capacity of producing vacuum is limited in parallel flow low level jet condenser.

• Similar to the counter jet technique, there is no need of extra pump to lift cooling water from source or cooling pond to condenser as it is alone by vacuum created in the condenser due to condensation of exhaust steam.
Exhaust steam

Cold water

Baffle plate

To air pump

Condensate

Condensate extraction pump

To boiler

Overflow

Hot well

Cooling pond

Fig. 3.118. Low Level jet Condenser (Parallel Flow).
Parallel Flow Low Level Jet Condenser
• **High Level or Barometric Jet Condenser**

• If a long pipe over 10 m, is closed at top end, filled with water, open at bottom and bottom is immersed in water, then atmospheric pressure would hold the water up in the pipe to a height of 10 m at sea level.

• On the basis of this principle, high level or Barometric jet condenser is designed. The figure below shows a high level jet condenser.
Fig. 3.120. High level jet Condenser (Counter Flow).
High level jet condenser.
• In this arrangement, the water outlet pipe from the condenser bottom comes straight vertically to the hot well which is placed at the ground level.

• Cooling water is fed to the condenser chamber by means of pump. The cooling water enters from the side near to the top of the condenser chamber. The exhaust steam enters from the side near to the bottom of the condenser. This is basically a counter flow jet condenser.

• Here, the steam travels upwards inside the condenser whereas the water jets falls from top. The condensates and cooling water comes to the hot-well through vertical tail pipe due to gravitational force.

• There is no need of extraction pump. The air, uncondensed steam are removed from the chamber by using a dry air pump at the top of the condenser. Here, the capacity and size of dry air pump is quite small as it has only to deal with air, and uncondensed steam, and it has not to handle with cooling water and condensed steam.
Ejector Condenser
Fig. 3.121. Ejector Condenser.
Ejector Condenser

• In this type of condenser, the momentum of falling water is utilized to extract or ejects air from condensates. The condenser chamber consists of a central vertical tube in which there is a string of many cones or converging nozzles. The exhaust steam enters from side way of the cylindrical condenser chamber.

• The central tube is provided with number of holes or steam ports. The cooling water falls on the top converging nozzle at high speed. This speed is attained by the falling water because the water falls from 2 to 6 m height. This water flowing down through the converging nozzles one by one. The steam enters into the nozzles via steam port. As this steam comes into contact with cooling water, it is condensed and creates partial vacuum. Due to this vacuum more and more steam enters into the vertical tubes through the steams ports and gets condensed and results further vacuum.
• The mixture of cooling water, condensed steam, uncondensed steam and wet air comes down to the bottom divergent nozzle as shown in the figure. In the diverging nozzles, the kinetic energy is partly transformed into pressure energy so that condensates and air will be discharged into the hot well against the pressure of the atmosphere.

• Ejector condenser is usually fitted with a non-return valve in exhaust steam inlet as shown to prevent a sudden backward rush of water into the turbine exhaust pipe in case of sudden failure of water supply to the condenser. An ejector condenser require more water than other jet water condenser. The cost is low and size is small. It is simple and reliable but only suitable for small power generation unit.
Surface Steam Condenser

• The **steam** can be condensed in **surface steam condenser** in two ways. Firstly, cooling water is passed through a series of tubes and steam passes over the tubes. Secondly, the steam is passed through a series of tubes and water is allowed to flow in the form of thin film outside the tubes.

• A surface condenser mainly consists of a cast iron shell. The shell is cylindrical in shape and closed at both end to form a water box. A tube plate is located between each cover head and the shell. A number of water tubes are fixed to the tube plates. The shell is provided with exhaust steam inlet at the top and condensed steam outlet at the bottom.
• The hot exhaust steam enters through the top inlet of the surface condenser shell; and cooling water enters into the inlet water box and then flows through the water tubes runs from one end to other end of the condenser shell as shown. Then it enters into the end water box and returns from this box to outlet water box via return water tubes.

• During this circulation, the heat is absorbed from exhaust steam by cooling water through the wall of the tubes. As a result, the steam ultimately becomes condensed and comes out through wet air outlet. This surface condenser required two pumps-

• One pump to circulate cooling water through the water tubes under pressure.

• One for extracting wet air, condensates from the bottom of the condenser shell.
• **Surface steam condensers** are of mainly two types:
  • Two flow condenser.
  • Multi flow condenser.
• In two flow steam condenser, cooling water travels twice once from inlet-water box to end water box and once from end water box to outlet water box.
• By providing more and more partitions in the water boxes, surface condenser can be made multi flow condenser like, 4 flow, 6 flow etc. In multi-flow process, the rate of heat exchange is rapid but the power required to circulate the cooling water is also more. According to the direction of flow of steam the surface steam turbine can be classified as-
  • Down flow, Central flow, Inverted flow, Regenerative type, and Evaporative type surface condenser.
Fig. 3.122. Down Flow Type.
• **Down Flow Surface Condenser**

• In Down flow surface condenser, steam enters on the top of the condenser vessel and it comes down over the cooling water pipes. the steam as a result is condensed and the condensate is extracted from the bottom by the condensate extraction pump.

• The temperature of condensate gets decrease as it passes downwards. Also the partial pressure of steam decreases from top to bottom of the steam condenser. The air exit is shielded from the down stream of the condensate by means of baffle plate and thus air is extracted with only a comparatively small amount of water vapour. As the air comes down, it is progressively cooled and becomes denser and hence it is extracted from the lowest convenient point.
Down Flow Surface Condenser
Central Flow Surface Condenser

• In this type of surface condenser the suction pipe of the air extraction pump is placed in center of the tubes nest, this causes the condensate to flow radially towards the center as shown by arrows in the figure.

The condensate leaves at the bottom where the condensate extraction pump is situated. The air is withdrawn from the center of the nest of tubes. This method is an improvement on the down flow type as the steam is directed radially inward by a volute casting around the tube nest it has thus access to the whole periphery of the tubes.
• **Inverted Flow Type Surface Condenser**

• Here, the air extraction pump is situated at the top. The steam enters near the bottom and goes upwards. The condensate extraction pump is situated at the bottom of the condenser.

• **Regenerative Type Surface Condenser**

• This type is applied to condensers adopting a regenerative method of heating of the condensate. After leaving the tube nest, the condensate is passed through the entering exhaust steam from the turbine thus raising the temp of the condensate, for use as feed water for the boiler.
• **Evaporate Steam Condenser**

• When the supply of cooling water is very limited, the evaporate type steam condenser is used. In this condenser the exhaust steam is circulated through a series of tubes and a thin film of cooling water is allowed to flow over these tubes. The condensed steam and wet air is extracted from the steam tube outlet by means of wet air pump.

• A natural or force air flow helps rapid evaporation of the film, which speeds up the condensation process. The water which is not evaporated, collected in a water tray from which it can be pumped back for reusing as cooling water. Evaporate type steam condenser requires minimum cooling water. Only the make up water required to supply to compensate evaporation. This type of steam surface condenser is suitable for small power plant.
Evaporate Steam Condenser
<table>
<thead>
<tr>
<th>Jet Condenser</th>
<th>Surface Condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>The process is faster</td>
<td>The process is slower</td>
</tr>
<tr>
<td>The process is simpler</td>
<td>The process is complex</td>
</tr>
<tr>
<td>The process is cheaper</td>
<td>The process is costlier</td>
</tr>
<tr>
<td><strong>The process is used where sufficient boiler feed water is available</strong></td>
<td><strong>The process is used where sufficient boiler feed water is not available and the condensed steam is reused as boiler feed water.</strong></td>
</tr>
<tr>
<td>The process is installed where cooling water is easily and cheaply made suitable for boiler feed.</td>
<td>The process is suitable where cooling water can not be easily made suitable for boiler feeding</td>
</tr>
<tr>
<td>In Jet condenser, the condensed steam, air, cooling water and uncondensed vapour and other gases are mixed up and can not be easily separated.</td>
<td>In surface condenser, the condensed steam is totally free from cooling water hence can be reused easily as boiler feed water.</td>
</tr>
</tbody>
</table>
Vacuum Efficiency

It is defined as the ratio of the actual vacuum to the maximum obtainable vacuum.

\[
\text{Vacuum Efficiency} = \frac{\text{Actual vacuum}}{\text{Maximum obtainable vacuum}}
\]

\[
= \frac{\text{Actual vacuum}}{\text{Barometric pressure} - \text{Absolute pressure of steam}}
\]

Maximum vacuum can be obtained when there is only steam and no air is present in the condenser.
Condenser Efficiency

It is defines as the ratio of difference between the outlet and inlet temperature of cooling water to the difference between the temperature corresponding to the vacuum in the Condenser and inlet temperature of cooling water.
Cooling Ponds and Cooling Towers

- The main steam condenser performs the dual function of removing this rejected energy from the plant cycle and keeping the turbine back pressure at the lowest possible level.
- The cooling water requirement is 50 times the flow of steam to the condenser in open type.
- In closed type the water requirement is as large as 5-8 kg/kWh.
- i.e, 1000MW station will require 100 thousand tons of water per day even with cooling towers.
- Source of cooling water is River or sea, Cooling ponds, Spray ponds and cooling towers.
Fig. 3.127. River water cooling system.
Cooling ponds

• These are the simplest of the devices for recooling of the cooling water.
  It consist of large, shallow pool into which hot water is allowed to come in contact with atm air.
The depth of cooling pond should be around 1 metre.
Types: Non directed flow natural cooling pond, Directed flow natural cooling pond

Advantages:
• Here no spray or other cooling device is employed thus keeping operating cost very low.
• Suitable where sufficient amount of circulating water is not available

For large power plant spray ponds should be used.
Fig. 3.128. Non-directed flow natural cooling pond.

Fig. 3.129. Directed flow natural cooling pond.
Spray Ponds

- In this system warm water received from the condenser is sprayed through the nozzles over a pond of large area & cooling effect is mainly due to evaporation from the surface of water.
- In this system sufficient amount of water is lost by evaporation and windage.
• Disadvantages of cooling and spray ponds

1. Considerably large area is required

2. High spray losses due to evaporation and windage

3. No control over the temperature of cooled water.

4. Low cooling efficiency as compared with cooling towers.
Cooling Towers

• In cooling tower water is made to trickle down drop by drop so that it comes in contact with the air moving in opposite direction. As a result of this some water is evaporated & is taken away with air. In evaporation the heat is taken away from the bulk of water, which is thus cooled.
• Factors affecting cooling of water in a cooling tower

1. Temp of air
2. Humidity of air
3. Size & height of tower
4. Velocity of air entering the tower
5. Accessibility of air to all parts of tower
6. Degree of uniformity in descending water
7. Arrangement of plates in tower
8. Temp of hot air
• Classification
  1. Timber
  2. Concrete (Ferro-concrete, multideck concrete hyperbolic) &
  3. Steel duct type

Also classified as
  1. Natural draught
  2. Mechanical draught
     2a. Forced draught
     2b. Induced draught
Natural draught cooling tower

• In this type hot water from the condenser is pumped to the troughs & nozzles situated near the bottom. Trough spray the water in the form of droplets into a pond situated at the bottom of the tower.

• The air enters the tower from air openings provided near the base, rises upward & takes up the heat of falling water. (Fig. hyperbolic tower)
• Advantages over mechanical draught towers:
  1. Low operating & maintenance cost.
  2. More or less trouble free operation
  3. Less ground area required.
  4. Can withstand winds of high speed as base is high (100-125m in dia) and self supported structures.
  5. Enlarged top allows water to fall out of suspension.

Disadvantages:
  1. High initial cost
  2. Its performance varies with seasonal change in DBT & RH of air.

Though initial cost is high but saving in fan power, longer life and less maintenance favour this tower. Also favourable over mechanical draught towers.
Mechanical draught cooling towers

• Here the draught of air for cooling is produced mechanically by means of propeller fans. These are built in cells or units & capacity depends upon it.

• It is similar to natural draught tower as far as interior design is concerned, but the sides of the tower are closed and form an air & water tight structure, except for fan openings at the base for the inlet of fresh air, and the outlet at the top for the exit of the air and vapours. There are hoods at the base projecting from the main portion of the tower where the fans are placed for forcing the air, into the tower.

• In induced draught the fans are placed at the top of the tower & they draw the air in through louvers extending all around the tower at its base.

• Figures in next page.
Fig. 3.132. Forced draught cooling tower.

Fig. 3.133. Induced draught cooling tower.
Comparison of Forced & Induced Draught towers

- Forced Draught towers

Advantages:
- More efficient than induced
- No problem of fan blade erosion (as it handles dry air only)
- More safe.
- Vibration and noise are minimum.

Disadvantages:
- Fan size is limited to 4 mtrs.
- Power requirement is high (double that of induced)
- In cold weather, ice is formed on nearby equipment & buildings or in the fan housing itself. The frost in the fan outlet can break the fan blades.
• Induced Draught towers

Advantages:
• Lower first cost
• Less space is required
• Tower is capable of cooling through a wide range.

Disadvantages:
• The air velocities through the packings are unevenly distributed & it has very little movement near the walls & centre of tower.
• Highest H.P. motor is required to drive the fan.
Comparison of Natural & Mechanical Draught towers

- Mechanical draught towers
  - **Advantages:**
    1. These require small land area & can be built at most locations.
    2. Fans give good control over the air flow & thus water temp.
    3. Less costly to install than natural ones.
  - **Disadvantages:**
    1. Fan power requirement and maintenance cost make them more expensive to operate.
    2. Local fogging and icing may occur in winter season.
Dry Cooling Towers

• Necessity of using dry cooling towers
  1. Thermal pollution problems
  2. The concentration of impurities increases in cooling towers so disposal of tower blow down becomes a serious problem.

The dry system rejects heat directly to the atm.

Types of dry cooling towers

1. Direct system: Here steam is passed on the cooling coils where it is condensed directly by means of air. Cooling coils constitute air cooled condenser.

Disadvantage: Large ducts are needed to convey steam to the exchanger coils to minimize pressure drop & limited to 300MW.

2. Indirect system: Here steam is condensed in a spray condenser by means of circulating water. The major part of the water from the condenser flows back to the cooling coils & an amount equal to the exhaust steam is directed back to boiler circuit. Applicable to all large unit sizes.
Fig. 3.134. Direct system.
Fig. 3.135. Indirect system.
Advantages of dry cooling system

• It solves the problem of thermal pollution.
• There is no evaporative loss of water as in wet type due to non direct contact of water with air.
• Power plant can be sited closer to the load center.
• There is min air pollution
• Environmental friendly like no fog, no blow down treatment, no windage loss of water, no evaporative loss, and no thermal discharge to water source.

Disadvantages:

• Most critical in warm climates
• Their performance is limited by DBT of air, so turbine exhaust temp is much higher resulting in substantial loss of turbine efficiency.
• Due to low ‘h’ these require enormous volumes of air hence large surface area, and hence less effective at high natural air temp.
Maintenance of cooling towers

Regular maintenance is very essential to achieve desired cooling & to reduce depreciation cost.

1. Fans, motors housings should be inspected time to time.

2. Motor bearings should be greased & gearboxes should be oiled regularly.

3. At least once in a year motor gear boxes should be checked for structural weakness.

4. Circulating water should be tested for hardness, and should be kept free from impurities to avoid scale formation and to avoid corrosive action.

5. Water spraying nozzles should be inspected regularly for clogging.
Air Leakage

• Sources of air

1. From atmosphere: At the joints of parts due to low pressure than atmospheric pressure. This can be reduced by design and vacuum seals.

2. Air also accompanies with steam from boiler, this depends how much it is treated/purified before feeding to boiler. However this amount is small.

3. In jet condensers, injection water carries little quantity of air. (0.5kg/10000 kg of water) & in surface condenser it is 5-15kg/10000 kg of water.
Effect of Air leakage in condenser

• Reduced thermal efficiency: which increases the back pressure & hence reduces heat drop, thus thermal efficiency lowered.
• Increased requirement of cooling water: leaked air lowers the partial pressure of steam which lowers saturation temp of a steam, which increases the latent heat. Hence requirement of cooling water increases
• Reduced heat transfer: as air has low ‘k’, hence surface area increases.
• Corrosion increases.
Methods of obtaining maximum vacuum

• By air pump: by extracting air and non-condensable gases.

1. **Wet air pump**: removes mixture of condensate and non-condensable gases.

2. **Dry air pump**: Which removes air only.

• By steam air ejector

• De-aeration of feed water.

• Air tight joints
THANK YOU