Condensers

The condenser is a two-phase flow heat exchanger (HEX) where the heat (generally latent heat) is removed by conversion of vapor into liquid with the help of coolant.

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Its main function in thermal power plant is to condense the exhaust stream from the turbine and thus recover the high-quality feed water for reuse in the plant.
INTRODUCTION

Why it is necessary...???

- Feed from condenser for boiler reduces the cost of power generation as the condensate is supplied at higher temperature.
- The deposition of salt in the boiler is prevented with the use of condensate instead of using the feed water from outer source which contains salt.
- Reduces the capacity of the feed water cleaning system.
- The use of condenser in steam power plant reduces the overall cost of generation by increasing the thermal efficiency of the power plant.
Thermodynamics point of view...

- The partial vacuum and low back pressure is developed in condenser. The specific steam consumption of the plant decreases as the available enthalpy drop or work developed per kg of steam increases with the decrease in back pressure by using condenser.

By lowering the condenser operating pressure, following will occur:

- Increased turbine output
- Increased plant efficiency
- Reduced steam flow (for a given plant output)
There are mainly two types:

**Indirect contact:** condensing vapor and coolant are separated by a solid surface
- shell-and-tube: condensation inside or outside, vertical or horizontal
- plate: limited applications
- air-cooled: condensation in tubes, air blown over tubes (usually finned)

**Direct contact:** condensing vapor and coolant are in direct contact
- vapor bubbled into a poof of liquid
- liquid sprayed into vapor
- packed-column: liquid flows as a film over a "packing material" against upward flow of vapor.
Note: Tubes are brass, cupro nickel, titanium or stainless steel. The tubes are expanded or rolled and bell mouthed at the ends in the tubesheets.

**Typical Power Plant Condenser**
Indirect / Surface Condenser

Diagram of an indirect surface condenser showing:
- Water outlet
- Steam inlet
- To ejector vacuum system
- Flanged cover plate
- Water inlet
- Baffles
- Tubesheet
- Condensate outlet
The surface condensers may be classified according to

(a) Number of water passes: single or multipass.
(b) Direction of condensate flow and tube arrangement: down flow, and central flow as shown below.
Mixing or Jet Type Condensers:

- The jet condensers are mainly divided as parallel flow and counter flow jet condensers.
- In parallel flow condensers, the steam and cooling water flow in the same direction whereas they flow in opposite directions in counter flow condensers.

Mixing type condensers are mainly classified into three categories depending upon the arrangement used for the removal of condensate as low level, high level and ejector condenser. These are rarely used in modern high capacity power plants.
The sources of air:
- 1. The air leaks through the joints, packings and glands into the condenser where the pressure is below the atmospheric pressure.
- 2. The feed water contains air in dissolved condition. The dissolved air gets liberated when the steam is formed and it is carried with the steam into the condenser.

The effects of air leakage:
- 1. It increases the pressure in condenser or back pressure of the prime-mover and reduces the work done per kg of steam.
- 2. The pressure of air lowers the partial pressure of steam and its corresponding temperature. The latent heat of steam increases at low pressure. Therefore, more quantity of cooling water is required to condense one kg of steam as quantity of latent heat removed is more.
There is greater possibility of under-cooling the condensate with the reduction in partial pressure of steam due to the presence of air. This phenomenon reduces the overall efficiency of the power producing plant.

3 The heat transfer rates are greatly reduced due to the presence of air because air offers high resistance to heat flow. This further necessitates the more quantity of cooling water to maintain the heat transfer rates. Otherwise, it reduces the condensation rate and further increases the back pressure of the prime mover.

Removal of Air:

It is obvious from the above discussion that the preventive measures should be taken to remove leaking air from the condenser to avoid its bad effects.

The air from the condenser is removed with the help of airpumps. The primary function of the air pump is to maintain the vacuum in the condenser which corresponds to the exhaust steam temperature by removing the air. Another function of the pump is to remove the condensate coming out from the bottom of the condenser.

An air-pump which removes both air and condensate together is called 'Wet Air-Pump' while the air-pump which removes only the moist air is known as 'Dry-Air-Pump'.
Dalton's law of partial pressure states that

“The total pressure exerted by a mixture of gases or a mixture of gas and vapour is equal to the sum of individual partial pressures of the constituents of the mixture; if individual partial pressures of the constituents of the mixture when individual alone occupies total volume, occupied by mixture having the same temperature of mixture.”

The total pressure in the condenser is the sum of the partial pressures of steam and air.

According to Dalton’s law of partial pressure

\[ p_t = p_s + p_\alpha \]
\[ V = \text{volume of condenser shell.} \]

\[ T = \text{Temperature of mixture (air + steams) in the condenser.} \]

\[ p_t = \text{Actual total pressure in the condenser.} \]

\[ p_s = \text{Partial pressure of steam in condenser.} \]

\[ p_a = \text{Partial pressure of air in condenser.} \]

\[ m = \text{Total mass of mixture (air + steam) in the condenser shell.} \]

\[ m_s = \text{Mass of steam in condenser shell.} \]

\[ m_a = \text{Mass of air in condenser shell.} \]

\[ \nu_s = \text{Specific volume of saturated water vapour at temperature } T \text{ and pressure } P_s. \]

\[ \nu_a = \text{Specific volume of air at temperature } T \text{ and Pressure } P_a. \]

\[ V = m_s \cdot \nu_s = m_a \cdot \nu_a. \]

\[ \frac{m_a}{m_s} = \frac{\nu_s}{\nu_a} \]
The mass of air per m$^3$ of the condenser shell

$$\frac{m_a}{V} = \frac{1}{\nu_a}$$

and the mass of water vapour per m$^3$ of the condenser shell

$$\frac{m_s}{V} = \frac{1}{\nu_s}$$

The total mass of mixture in the condenser shell can be written as

$$m = m_a + m_s$$

$$= m_a \left( 1 + \frac{m_s}{m_a} \right) = m_a \left( 1 + \frac{\nu_a}{\nu_s} \right)$$

or

$$m = m_s \left( 1 + \frac{m_a}{m_s} \right) = m_s \left( 1 + \frac{\nu_s}{\nu_a} \right)$$