Chapter 4

Steam Condensers Design

Introduction

Steam condensers are devices in which the exhaust steam from the steam turbine is condensed by means of cooling water. Condensation can be done by removing heat from exhaust steam using circulating cooling water. During condensation, the working substance (steam) changes its phase from vapour to liquid and rejects latent heat as shown in Figure 1.

The primary object of a condenser is to maintain a low pressure on the exhaust side of the rotor of steam turbine. This enables the steam to expand to a greater extent which results in an increase in available energy for conversation into mechanical work. The secondary object of condenser is to supply to the boiler pure and hot feed water, as the condensed steam which is discharged from the condenser and collect in a hot well can be used over again as feed water for the boiler.

The use of a condenser in a power plant is to improve the efficiency of the power plant by decreasing the exhaust pressure of the steam below atmospheric pressure. Another advantage of the condenser is that the steam condensed may be recovered to provide a source of pure feed water to the boiler and reduce the water softening capacity to a considerable extent.

Advantages of a condenser in a steam power plant

The main advantages of incorporating a steam condenser in a steam power plant are as follows:

- It increases the efficiency of the power plant due to increased enthalpy drop.
- It reduces back pressure of the steam which results in more work output.
- It reduces temperature of the exhaust steam which also results in more work output.
- The condensed steam can be reused as feed water for boiler which reduces the cost of power generation.
- The temperature of the condensate is higher than that of the fresh water which reduces the heat supplied per Kg of steam produced.

Function of condenser

The main function of condenser is to convert gaseous form of exhaust steam into liquid form at a pressure of below atmosphere. Cooling medium is used water to convert steam into water.

Others important functions of condensers:

- Function of the condenser is to create a vacuum by condensing steam
- Remove dissolved non - condensable gases from the condensate.

- Providing a leak tight barrier between the high grade condensate contained within the shell and the untreated cooling water.
- Providing leak tight barrier against air ingress, preventing excess back pressure on the turbine.

Elements of a steam condensing plant

The main elements of a steam condensing plants are:

- **A condenser** in which the exhaust steam is condensed
- Supply of **cooling water** for condensing exhaust steam
- **A pump** to circulate the cooling water in case of a surface condenser
- **A pump** called the wet air pump to remove the condensed steam (condensate) the air, and uncondensed water vapour and gases from the condenser (separate pump may be used to remove air and condensed steam)
- **A hot well** where the condensed steam can be discharged and from which the boiler feed water is taken
- An arrangement (**cooling pond or cooling tower**) for cooling the circulation water when a surface condenser is used and the supply of water is limited

Types of condensers

The steam condensers are classified as follows:

1. **Jet condensers (mixing type condensers)**
   a. Parallel flow jet condenser
   b. Counter flow jet condenser (low level)
   c. Barometric or high level jet condenser
   d. Ejector condenser
2. **Surface condensers (non mixing type condensers)**
   a. Down flow surface condenser
   b. Central flow surface condenser
   c. Regenerative surface condenser
   d. Evaporative condenser

2.19 CONDENSER VACUUM AND ITS MEASUREMENT

The pressure inside the condenser is below the atmospheric pressure and is called vacuum pressure. The vacuum in the condenser is the difference between the barometric pressure and the absolute pressure in the condenser. The difference between the barometer reading and the vacuum gauge reading gives the absolute pressure in the condenser as shown in Figure 2.36.

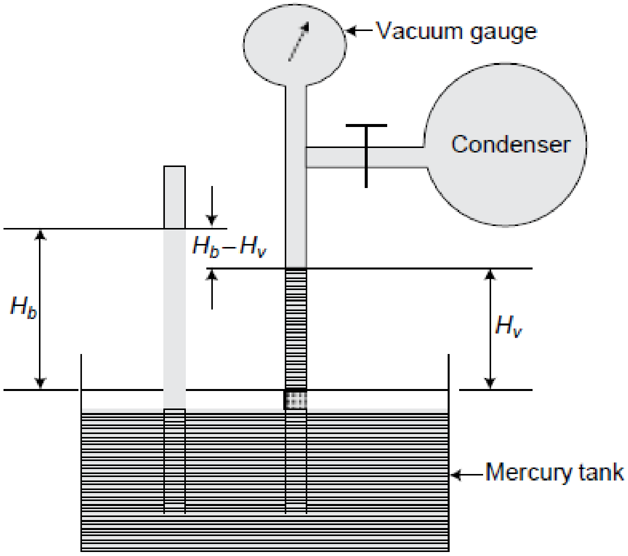

Fig. 2.36 Vacuum Measurement

Let the vacuum in the condenser be equivalent to H_v cm of mercury which is measured by vacuum gauge and the barometric pressure is equivalent to H_b cm of mercury.

Therefore, absolute pressure = $(H_b - H_v)$ cm of Hg

We know that 76 cm of Hg = 1.01325 bar

Therefore, pressure equivalent to 1 cm of Hg = (1.01325/76) = 0.0133322 bar

If it is desired to know the absolute pressure in the condenser then the barometric reading and gauge reading must be known. If barometric reading is 76 cm of Hg and gauge reading is 68 cm of Hg then the absolute pressure in the condenser will be

$$= (76 - 68) = 8 \text{ cm of Hg}$$

$$= 8 \times 0.0133322 = 0.10666 \text{ bar.}$$

The barometric head H_b varies according to atmospheric conditions, and hence the absolute pressure in the condenser is a function of the barometric pressure.

If the barometric reading (atmospheric pressure) is 76 cm of Hg at sea-level then the corrected vacuum in the condenser is given by,

$$= 76 - \text{absolute pressure in the condenser in cm of Hg}$$

$$= 76 - (H_b - H_v) \tag{2.39}$$

2.21 DALTON'S LAW OF PARTIAL PRESSURES

The law states that the total pressure exerted by a non-reactive mixture of gases or a mixture of gas and vapor is equal to the sum of partial pressure of the individual constituents of the mixture at the same temperature (T).

The partial pressure of each constituent of the mixture is the pressure exerted by the constituent taken separately in the same volume (V) of the vessel as that of mixture and at the same temperature. This is explained by taking the following example as shown in Figure 2.37.

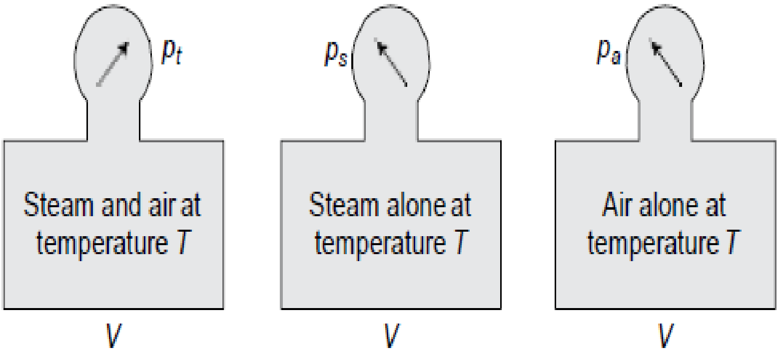

Fig. 2.37 Dalton's Law of Partial Pressure

The total pressure (p_t) in the condenser or vessel is the sum of the partial pressures of steam (p_s) and air (p_a).

According to Dalton's law of partial pressure,

$$p_t = p_s + p_a$$

or

$$p_a = p_t - p_s$$

The vacuum gauge reads the total pressure in the condenser, i.e., p_t. The steam pressure p_s can be known from the steam table corresponding to condenser temperature. As p_t and p_s are known thus p_a can be determined.

2.22 VACUUM EFFICIENCY

The vacuum efficiency is a measure of the degree of perfection of maintaining a desired vacuum in the condenser. The ideal vacuum means the vacuum due to steam alone when air is absent. Under such a condition total pressure in the condenser will reach to the pressure of steam corresponding to the saturation temperature of the steam.

Let

p_s = Saturation pressure of steam in bar corresponding to the temperature of water entering the condenser,

p_t = Total pressure of air and steam

$= p_s + p_a$, and

p_b = Barometric pressure or atmospheric pressure

$$\text{Ideal vacuum} = p_b - p_s \tag{2.40}$$

$$\text{Actual vacuum} = p_b - p_t$$

$$= p_b - (p_a + p_s) \tag{2.41}$$

The vacuum efficiency (h_{vacuum}) is defined as the ratio of actual vacuum recorded by the vacuum gauge to the ideal vacuum.

$$h_{vacuum} = \frac{\text{Actual vacuum recorded by gauge}}{\text{Ideal vacuum}}$$

$$= \frac{p_b - (p_a + p_s)}{p_b - p_s} = \frac{p_b - p_t}{p_b - p_s} \qquad \text{`(2.42)}$$

If there is no air leakage into the condenser then $p_a = 0$ and hence the vacuum efficiency becomes 100%. The vacuum efficiency depends upon the effectiveness of the air cooling and the rate at which the air is removed by the air pump. Generally, the vacuum efficiency is about 98% to 99%.

2.23 CONDENSER EFFICIENCY

In an ideal condenser the steam should give only its latent heat to the circulating water so that temperature of the condensate becomes equal to the saturation temperature corresponding to the condenser pressure. It means there should be no undercooling of the condensate. Maximum temperature to which the cooling water can be raised is the condensate temperature. The condenser efficiency ($h_{condenser}$) is then defined as the ratio of actual rise in the temperature of the cooling water to the maximum possible rise, i.e.,

$$h_{condenser} = \frac{T_2 - T_1}{T_s - T_1} \qquad (2.43)$$

where T_2 = Outlet temperature of cooling water, T_1 = Inlet temperature of cooling water, and T_s = Saturation temperature corresponding to condenser temperature.

2.24 MASS OF COOLING WATER REQUIRED IN A CONDENSER

In a jet condenser the exhaust steam and the cold water mix directly, so the resulting temperature of the condensed steam and water is the same at its outlet. But in a surface condenser the temperature of the condensate and the circulating water may differ.

Let m = Quantity of circulating water in kg/h, m_s = Quantity of steam condensed in kg/h, T = Temperature of the wet exhaust steam in °C, T_c = Temperature of the condensate in °C, h_f = Sensible heat or enthalpy of water at T °C, h_{fg} = Latent heat or enthalpy of evaporation of steam at T°C, x = Dryness fraction of exhaust steam, T_1 = Inlet temperature of cooling water in °C, T_2 = Outlet temperature of cooling water in °C, h_c = Sensible heat or enthalpy of condensate, c_w = Specific heat of cooling water.

Now for a condenser,

Heat given up by steam = Heat absorbed by cooling water

For a surface condenser,

$$m_s \times (h_f + xh_{fg} - h_c) = c_{pw} \times m \times (T_2 - T_1)$$

\

$$m = \frac{m_s \times (h_f + xh_{fg} - h_c)}{c_{pw} \times (T_2 - T_1)} \qquad (2.44)$$

For a jet condenser,

$$T_2 = T_c$$

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$$m = \frac{m_s \times (h_f + xh_{fg} - h_c)}{c_{pw} \times (T_c - T_1)} \qquad (2.45)$$

6. A Surface condenser is designed to handle 17600 kg of steam per hour. The steam enters at 0.2 bar pressure and quality is 0.88. Cooling water enters at 40°C and leaves at 50°C. The condenser is made of 23 mm inside diameter tubes. The velocity of water in the tube is 1.8 m/sec. Calculate the number of tubes that must be used in the condenser. The temperature of the condensed is 60 °C.

Given data

Mass of steam,	m_s= 17600 kg/hr.
Pressure of steam,	$p = 0.2$ bar
Dryness fraction,	$x = 0.88$
Condensate temperature,	t_c= 60 °C
Inlet temperature of cooling water,	t_1= 40°C
Inlet temperature of cooling water,	t_2= 50°C
Diameter of the tube,	d= 23 mm = 0.023 m
Velocity of water,	C=1.8 m/sec

To Calculate

Number of tubes used in the condenser, n.

Solution

NUMBER OF TUBES REQUIRED

$$n = \frac{4\ X\ m_w}{1000\ X\ \pi\ X\ C\ X\ d^2}$$

From Steam Table at p = 0.2 bar

$$h_f = 251.5 \text{ kJ/kg}$$

h_{fg}= 2358.4 kJ/kg

From Steam Table at t_1=40°C; h_{f1}= 167.5 kJ/kg

From Steam Table at t_2=50°C; h_{f2}= 209.3 kJ/kg

From Steam Table at t_c=60°C; h_c= 251.1 kJ/kg

Enthalpy of steam entering condenser,

h_{wet} = h_f + (x. h_{fg}) kJ/kg

= 251.5 + (0.87 x 2358.4)

h_{wet} = 2303.308 kJ/kg

Mass of water Required

$$m_w = \frac{m_s(h_{wet} - h_c)}{(h_{f2} - h_{f1})} \text{ kg/hr}$$

$$m_w = \frac{17600(2303.308 - 251.1)}{(209.3 - 167.5)}$$

$$\mathbf{m_w = 864087.57894 \text{ kg/hr}}$$

= 240.024 kg/s

Number of tubes $n = \frac{4 X m_w}{1000 X \pi X C X d^2}$;

$$n = \frac{4 X 240.0243}{1000 X \pi X 1.8 X 0.023^2}$$

n = 321.11 = 321 (round of value)

Result

Number of tubes, n = 321.