POSTAL Book Package 2023

Mechanical Engineering

Conventional Practice Sets

Power Plant Engineering

Contents

MADE EASY Publications

1 CHAPTER Steam Generators

Practice Questions : Level-I

Q.1 A boiler producing 2000 kg/hr of steam with enthalpy content of 2426 kJ/kg from feed water at temperature 40°C (liquid enthalpy = 168 kJ/kg). What is the equivalent evaporation in kg/hr? (enthalpy of vaporization of water at 100°C = 2258 kJ/kg)

Solution:

Given data: Rate of steam producing, m_s = 2000 kg/hr; Specific enthalpy of feed water, h_f = 168 kJ/kg; Specific enthalpy steam, h = 2426 kJ/kg; Enthalpy of vaporization of water, h_{fg} = 2258 kJ/kg

we know that,

$$\text{Equivalent evaporation,} \quad m_e = \frac{\text{Total heat required to evaporated feed water}}{\text{Latent heat of steam at 100°C}}$$

$$= \frac{m_s(h - h_f)}{h_{fg}} = \frac{2000(2426 - 168)}{2258} = \mathbf{2000\ kg/hr}$$

Q.2 Economizer of a power boiler operating at 150 bar pressure receives 500 kg/s of water from boiler feed pump with specific enthalpy of 340 kJ/kg. Superheated steam leaves the boiler at 550°C with specific enthalpy of 3448.6 kJ/kg. Efficiency of the boiler is 90% and calorific value of the coal used is 10000 kJ/kg. Find the following :

(i) Heat added in economizer, evaporator and superheater in kJ/s
(ii) Percentage of heat added in economizer, evaporator and superheater out of total heat
(iii) Rate of coal consumption in kg/s

Also draw T-s plot showing the position of different components and heat added.

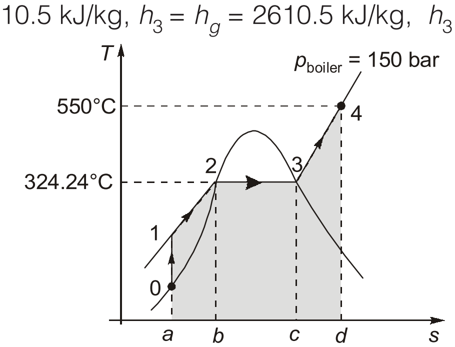
For 150 bar pressure, use the following table :

p_s(bar)	T_s(°C)	h_f(kJ/ kg)	h_{fg}(kJ/ kg)	h_g(kJ/ kg)
150	324.24	1610.5	1000	2610.5

Solution:

Given data: p_{boiler} = 150 bar; m = 500 kg/s; h_1 = 340 kJ/kg; h_4 = 3448.6 kJ/kg
η_{boiler} = 90%; CV = 10000 kJ/kg,

From steam table; $h_2 = h_f$ = 1610.5 kJ/kg, $h_3 = h_g$ = 2610.5 kJ/kg, $h_3 - h_2$ = 1000 kJ/kg



(i)

$$Q_{12} = Q_{economizer} = \dot{m}(h_2 - h_1) = 500\ (1610.5 - 340) = 635250 \text{ kJ/s}$$

$$Q_{23} = Q_{evaporator} = \dot{m}(h_3 - h_2) = 500\ (1000) \text{ kJ/s} = 500000 \text{ kJ/s}$$

$$Q_{34} = Q_{superheater} = \dot{m}(h_4 - h_3) = 500\ (3448.6 - 2610.5) \text{ kJ/s}$$

$$= 419050 \text{ kJ/s}$$

$$\text{Total heat added} = Q_{12} + Q_{23} + Q_{34} = 1554300 \text{ kJ/s}$$

(ii)

Component	Heat added (kJ/s)	Percentage %
Economizer	635250	40.87
Evaporator	500000	32.17
Superheater	419050	26.96

(iii) Rate of coal consumption,

$$\eta_{boiler} = \frac{Q_{total}}{\dot{m}_{coal} \times (CV)}$$

$$0.9 = \frac{1554300}{\dot{m}_{coal} \times 10000}$$

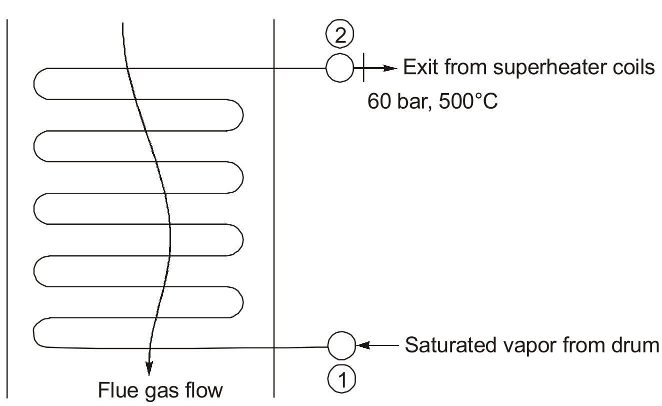
$$\dot{m}_{coal} = 172.7 \text{ kg/s}$$

Q.3 A superheater is to be designed using metallic coils (heat flux 150 kW/m^2) of inside diameter 50 mm and wall thickness 5 mm. The steam leaving the superheater coils is at 60 bars, 500°C and flows at a velocity of 10 m/s. If the steam mass flow rate is 90 kg/s, find the number and length of coils. For steam at 60 bars, take the following values – dry saturated steam h = 2784.3 kJ/kg, at 500°C superheated steam temperature h_{sup} = 3422.2 kJ/kg and specific volume v_{sup} = 0.05665 m^3/kg. The steam enters the superheater as dry and saturated.

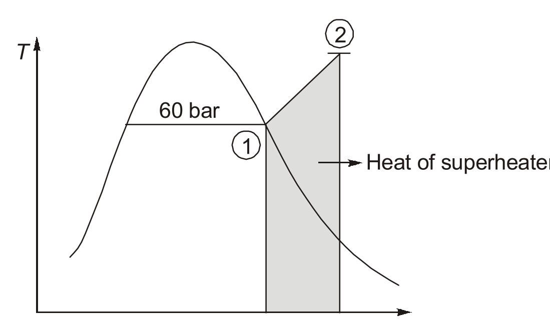
Solution:

Given data: Heat flux, $\dot{q}$ = 150 kW/m^2; d_i = 50 mm = 0.05 m,

Velocity, V = 10 m/s; $\dot{m}_s$ = 90 kg/s



Schematic of Superheater coils



Process on *T-s* coordinate

As given, $h_1 = h_g$ = 2784.3 kJ/kg, h_2 = 3422.2 kJ/kg and specific volume, v_2 = 0.05665 m^3/kg

Heat absorption rate in superheater coils,

$$\dot{Q} = \dot{m}_s(h_2 - h_1) = 90(3422.2 - 2784.3) = 57411 \text{ kW}$$

$$\text{Surface area required} = \frac{57411}{150} = 382.74 \text{ m}^2 \qquad [\text{As, } \dot{Q} = \dot{q} \times A]$$

$$\text{From continuity equation, } \dot{m}_s = \rho_1 A_1 V_1 = \rho_2 A_2 V_2 = \left(n \frac{\pi}{4} d_i^2\right)\frac{V_2}{v_2} = 90 \text{ kg/s}$$

[where 'n' is the number of superheater coils]

$$n = \frac{4 \times 90 \times 0.05665}{\pi \times (0.05)^2 \times 10} = 259.664 \simeq 260$$

Number of superheater coils, n = 260

As, Surface area, $A_0 = 382.74 = n \pi d_0 l$

d_0 = outer diameter = 50 + 2 × 5 = 60 mm [As thickness is 5 mm]

$$\text{Length of one coil} = \frac{382.74}{260 \times \pi \times 0.06} = 7.8 \text{ m}$$

Q.4 What is the function of an economiser in a thermal power plant? Why are the economiser tubes often provided with fins on the gas side? Explain.

Solution:

An economizer is a heat exchanger which raises the temperature of the feed water leaving the highest pressure feedwater heater to about the saturation temperature corresponding to the boiler pressure. This is done by the hot flue gases exiting the last superheater or reheater at a temperature varying from 370°C to 540°C. Economizers makes the utilization of hot flue gases in heating feedwater higher efficiency and better economy and hence this heat exchanger is known as economizer. Modern economizers are open designed to allow some boiling of the feedwater in the outlet sections, upto 20 per cent quality at full power, less at part loads. They are often termed as "steaming economizers".

Economizer tubes are commonly 45-70 mm in outside diameter and are made in vertical coils of continuous tubes connected between inlet and outlet headers with each section formed into several horizontal paths connected by 180° vertical bends. The coils are installed at a pitch of 45 of 50 mm spacing, which depends on the type of fuel and ash characteristics.

The gas-side heat transfer coefficient is much less than the water-side heat transfer coefficient. To compensate this, the outer surface of the tubes (Gas-side) are often provided with fins to increase the surface area of the heat transfer and improves effectiveness of economizer.

Practice Questions : Level-II

Q.5 A coal-based 660 MW capacity thermal power plant is having overall efficiency of 42%. It uses 600 kg/s of steam for running the turbine. Coal used in the power plant is having calorific value of 10000 kJ/kg. Fuel to air ratio is 1 : 10 for combustion in the boiler. Find the following :

(i) Specific steam consumption in kg/kWh

(ii) Mass flow rate of coal required in Tph (Tonnes per hour)

(iii) Mass flow rate of air required for combustion in kg/s

(iv) Heat required to be supplied to generate one unit of power (in kJ/kWh)

(v) Coal required to be supplied to generate one unit of power (in kg/kWh)

Solution:

Given data: Overall efficiency, η_0 = 42%; Capacity of thermal power plant, P = 660 MW,

Mass flow rate of steam, $\dot{m}_s$ = 600 kg/s, Calorific value of coal, $(CV)_f$ = 10000 kJ/kg,

Air fuel ratio, $\dot{m}_a : \dot{m}_f = 10 : 1$

We know that,

$$\dot{m}_s \times W_{net}(\text{kJ/kg}) = 660 \times 10^3 \text{ kW}$$

$$W_{net} = \frac{660 \times 10^3}{600} = 1100 \text{ kJ/kg (of steam)}$$

(i) Specific steam consumption $= \dfrac{3600}{W_{net}} = \dfrac{3600}{1100} = 3.273 \text{ kg/kWh}$

(ii) Total heat supplied $= \dfrac{660}{\eta_0} \text{ MW}$

$$\dot{m}_f \times (CV)_f = \frac{660 \times 10^3}{0.42} \text{ kW}$$

$$\dot{m}_f = \frac{660 \times 10^3}{0.42 \times 10000} = 157.142 \text{ kg/s}$$

Mass flow rate of coal required, $\dot{m}_f$ = 565714.30 kg/hour = 565.714 tonne per hour

(iii) Mass flow rate of air required = (AFR) × $\dot{m}_f$ = 10 × 157.143 = 1571.43 kg/s

(iv) Heat required for unit power generation $= \dfrac{1 \times 3600}{0.42} \text{ kJ/kWh} = 8571.4286 \text{ kJ/kWh}$

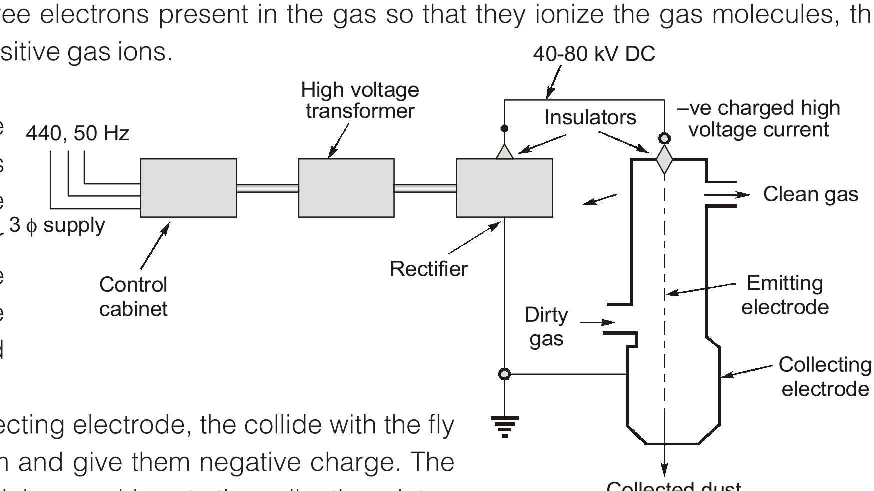
(v) Coal required for unit power generation $= \dfrac{565.714 \times 10^3}{(660) \times 10^3} = 0.857 \text{ kg/kWh}$

Q.6 **Explain the working of electrostatic precipitator and discuss variation of its collection efficiency with operating parameters like collector area, migration velocity and mass flow rate.**

Solution:

Electrostatic Precipitator: The principal components of an electrostatic precipitator (ESP) are two sets of electrodes insulated from each other. The first set is composed of rows of electrically grounded vertical parallel plates, called the collection electrodes, between which the dust-laden gas flows. The second set of electrodes consists of wires, called the discharge or emitting electrodes that are centrally located between each pair of parallel plates. The wires carry a unidirectional negatively charged high-voltage current from an external DC source. The applied high voltage generates a unidirectional, non-uniform electrical field. When that voltage is high enough, a blue luminous glow called a corona, is produced around them. Electrical forces in the corona accelerate the free electrons present in the gas so that they ionize the gas molecules, thus forming more electrons and positive gas ions.

The positive ions travel to the negatively charged wire electrodes. The electrons follows the electrical field toward the grounded electrodes but their velocity decreases toward the plates. Gas molecules capture the low velocity electrons and become negative ions.



As these ions move to the collecting electrode, the collide with the fly ash particles in the gas stream and give them negative charge. The negatively charged fly ash particles are driven to the collecting plate.

Collected particulate matter must be removed from the collecting plates on a regular schedule to ensure efficient collector operation. Removal is usually accomplished by a mechanical hammer scrapping system.