MECHANICAL ENGINEERING

Power Plant Engineering

Comprehensive Theory
with Solved Examples *and* Practice Questions

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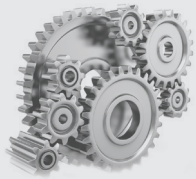
Power Plant Engineering



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1

Steam Generators

1.1 INTRODUCTION

A steam generator generates steam at the desired rate at the desired pressure and temperature by burning fuel in its furnace. A steam generator is a complex integration of furnace, superheater, reheater, boiler or evaporator, economiser and air preheater along with various auxiliaries such as pulverizers, burners, fans, stokers, dust collectors and precipitators, ash handling equipment and chimney or stack. The boiler (or evaporator) is that part of the steam generator where phase change (or boiling) occurs from liquid (water) to vapour (steam), at constant pressure and temperature. However, the term "boiler" is traditionally used to mean the whole steam generator.

The selection of type and size of a steam generator depends on the following factors:

1. The power required and working pressure.
2. The geographical position of power house.
3. The fuel and water available.
4. The probable load factor.

1.2 BOILER

A boiler is a closed vessel in which steam is produced from water by combustion of fuel at a constant pressure. According to ASME (American Society of Mechanical Engineers), a steam generator or a boiler is defined as "a combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vapourised". Boiler loads, or the capacity of steam boilers, are often rated in Boiler Horse Power (BHP), lbs of steam delivered per hour, or BTU.

1.2.1 Boiler Terms

- **Shell:** The shell of a boiler consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell ends are closed with the end plates.
- **Setting:** The primary function of setting is to confine heat to boiler and form a passage for gases.
- **Grate:** It is the platform in the furnace upon which fuel is burnt and it is made of cast iron bars.
- **Mountings:** Mountings are the safety devices such as steam stop valve, safety valves, fusible plug, blow-off cock, pressure gauges, water level indicator.
- **Accessories:** Accessories are employed to increase the efficiency of the plant such as superheaters, economisers, feed pumps etc. They are the integral parts of a boiler.
- **Foaming:** Formation of steam bubbles on the surface of boiler water due to high surface tension of water.

- **Scale:** A deposit of medium to extreme hardness occurring on water heating surface of a boiler.
- **Blowing off:** The removal of the mud and other impurities of water from the lowest part of the boiler is called as 'blowing off'.
- **Lagging:** Blocks of asbestos or magnesia insulation wrapped on outside of a boiler shell or steam piping.

NOTE: It should be noted the a boiler horsepower is 13.1547 times a normal horsepower.

1.3 CLASSIFICATION OF BOILERS

1.3.1 Externally and Internally Fired Boilers

- In case of externally fired boilers, the furnace is placed outside the boiler shell.
  Example: Babcock and Wilcox boiler, Stirling boiler, etc.
- In case of internally fired boilers, the furnace is located inside the boiler shell.
  Example: Cochran, Lancashire boiler, etc.

1.3.2 Forced Circulation and Natural Circulation

- In forced circulation boiler, the circulation of water is done by a pump.
  Example: Velox, Lamont, Benson boiler, etc.
- In natural circulation boilers, the circulation of water takes place due to natural convection currents.
  Example: Lancashire, Cornish, Locomotive, Babcock & Wilcox boiler, etc.

1.3.3 High Pressure and Low Pressure Boilers

- The boilers which produce steam at pressures of 80 bar and above are called high pressure boilers.
  Example: Babcock & Wilcox, Velox, Lamont, Benson boilers.
- The boiler which produce steam at pressure below 80 bar are called low pressure boilers.
  Example: Cochran, Cornish, Lancashire, Locomotive boilers, etc.

1.4 FIRE TUBE BOILER

In this type of boiler, the hot gases are passed through the tubes and water surrounds the tubes.

Example: Cochran, Lancashire, Cornish and Locomotive boilers.

Advantages :

Fire tube boilers have certain inherent advantages like :

1. Low maintenance cost
2. Reliability in operation
3. Need of only unskilled or semi-skilled labour
4. Less draught required, and
5. Quick response to load changes, pressure changes.

- **Drawbacks:** Definite size and steam pressure limitations in its basic design.

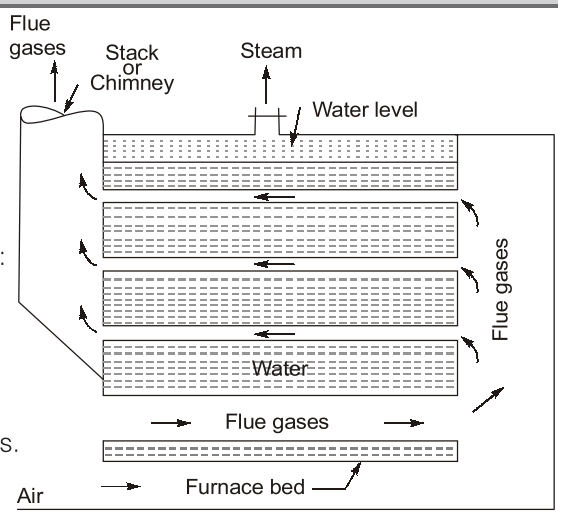


Figure: Fire-tube boiler

Tensile stress: $\sigma = \frac{pd}{2t}$ ...(1.1)

where, σ = Tensile stress (N/m^2); p = Gauge pressure (N/m^2); d = Internal diameter of the shell (m); t = Thickness of wall (m)

- Fire tube boilers are not suitable for producing large quantities of steam at higher pressures. From equation (1.1), it is clear that both higher pressures and larger sizes means larger wall thickness. Thus, high pressures and large diameters lead to prohibitively thick shells and thicker the shell, the higher the cost.
- A fire tube boiler is used in small power plants.

1.5 WATER TUBE BOILER

In this type of boiler, the water is inside the tubes and hot gases surrounds them. This boiler attains high pressures, as well as high-steam capabilities can be achieved. This is because of condensed tangential pressure on tubes which is known as hoop stress. The working principle of water tube boiler is thermal siphoning (circulation of natural water).

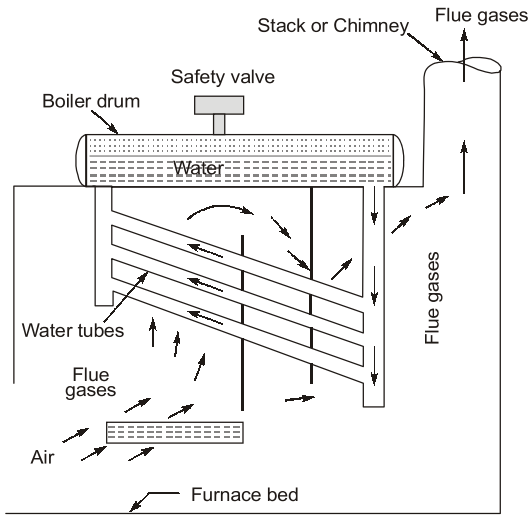


Figure: Water-tube boiler

Example: Babcock and Wilcox, Stirling, Yarrow boiler etc.

1.5.1 Straight-tube Boiler

The water-tube boiler went through several stages of development. The earliest design employed straight tubes rolled into headers at each end, since straight tubes could be made, installed and replaced easily. The tubes were of 75 to 100 mm outer diameter, inclined upward at about 15° to the horizontal and staggered. They have less accessibility and poorer inspection capability. Inadequate design and imperfect fabrication of handhole caps resulted in much leakage. Also circulation is sluggish due to low head in straight-tube boiler.

1.5.2 Bent-tube Boiler

In a bent-tube boiler, the tubes were so bent that they entered and left the drums radially. Bent-tube boilers offers many advantages over the straight-tubes boilers, the notable among them being greater accessibility for inspection, cleaning and maintenance, they can operate at higher steaming rates and deliver drier steam.

1.5.3 Heat Absorption in Water-tube Boilers

In a water-tube boiler, feedwater is heated in three kinds of heat exchangers. viz., economizer, evaporator and superheaters. For each kg of steam formed, the heat absorbed in the economiser (in the liquid phase), in the evaporator (liquid to vapour transition or the latent heat of vaporization), and in the superheater (in the vapour or gas phase) are given by

$$Q_{eco} = h_2 - h_1$$
$$Q_{eva} = h_3 - h_2$$
$$Q_{SH} = h_4 - h_3$$

The percentage of total heat absorbed in the economizer, evaporator and superheater are

$$\%\ \text{economizer} = \frac{Q_{eco}}{Q_{eco} + Q_{eva} + Q_{SH}} \times 100 = \frac{h_2 - h_1}{h_4 - h_1} \times 100$$

$$\%\ \text{evaporator} = \frac{Q_{eva}}{Q_{eco} + Q_{eva} + Q_{SH}} \times 100 = \frac{h_3 - h_2}{h_4 - h_1} \times 100$$

$$\%\ \text{superheater} = \frac{Q_{SH}}{Q_{eco} + Q_{eva} + Q_{SH}} \times 100 = \frac{h_4 - h_3}{h_4 - h_1} \times 100$$

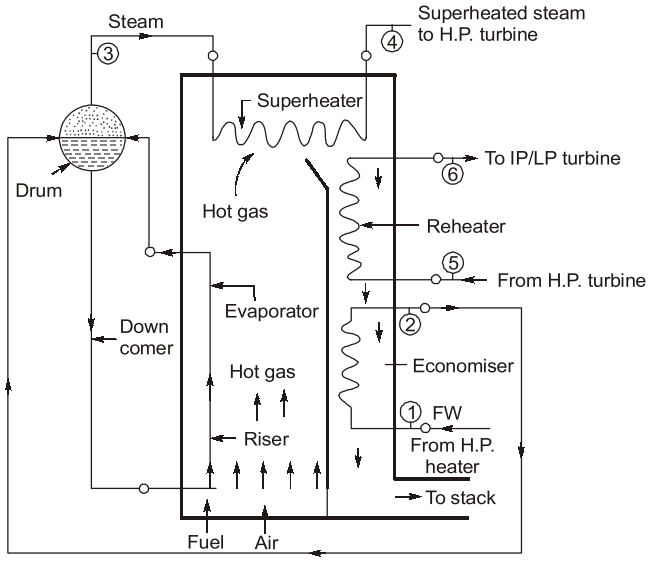


Figure: Heat absorption in a water-tube boiler

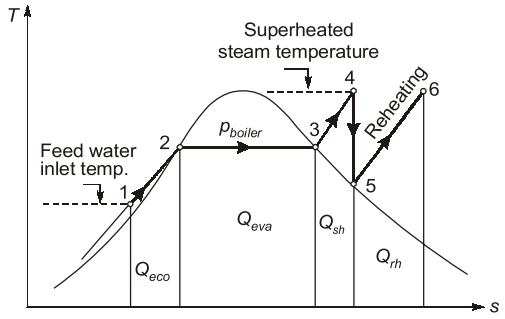


Figure: T-s Representation of heating process in a water- tube boiler

NOTE: The fraction of total heat absorbed in superheaters alone may be as high as 60% in a modern boiler.

1.5.4 Circulation

The flow of water and steam within the boiler circuit is called **circulation**. If circulation is caused by **density difference**, the boiler is said to have **natural circulation**. If it is caused by **a pump**, it has **forced or controlled circulation**. A simple downcomer riser circuit connecting a drum and a header is shown in figure. The **downcomer, which is insulated, is outside the furnace** and the **riser is inside it**. Nearly saturated water falls by gravity from drum through the downcomer into the bottom header.

- The pressure head available for natural circulation is given by

$$\Delta p = gH(\rho_f - \rho_m)$$

where, H = Height of riser,
ρ_f = Density of saturated water in down comer,
ρ_m = Mean density of steam water mixture in riser or

$$\rho_m = \frac{\rho_{bottom} + \rho_{top}}{2}$$

Now, $\rho_{bottom} = \rho_f$

and $\rho_{top} = \frac{1}{v_{top}}$

$v_{top} = v_f + x v_{fg}$

i.e., $\Delta p \propto (\rho_f - \rho_m)$

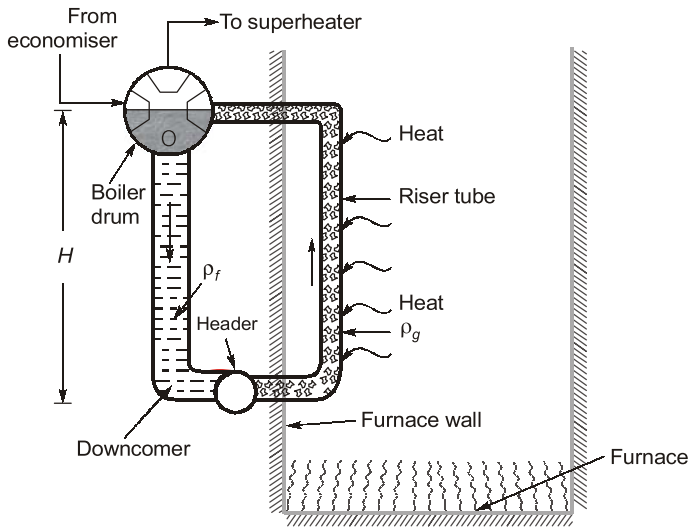


Figure: Natural circulation in a down comer riser circuit

- Higher is the density difference, more will be the pressure head available for natural circulation.

  However, the density differential decreases as pressure increases.
- At the critical pressure, $v_g = v_f$ and $\rho_g = \rho_f$ and there can be no natural circulation.
- In the event of boiler pressure exceeding 180 bar, the density difference $(\rho_f - \rho_m)$ becomes very small, which means poor natural circulation and thus force circulation becomes essential.
- Natural circulation is possible upto **180 bar**.

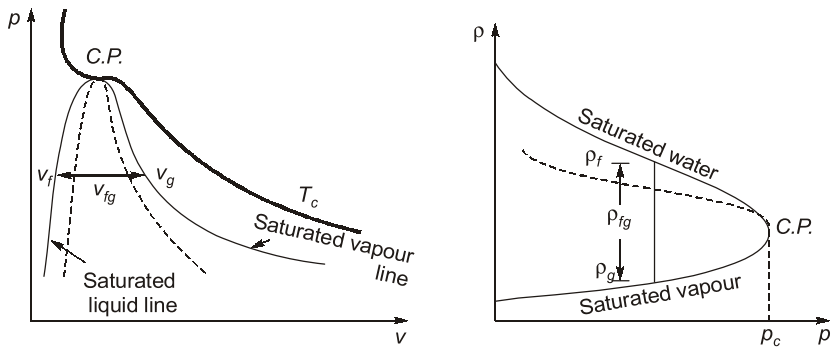


Figure: Differential in specific volume and density varying with pressure

Riser installed all around the four walls of the furnace acts as cooling tubes or a water wall and carry away the heat from the furnace at the same rate at which heat is released in it by the burning of fuel. If the circulation is not adequate, the rate at which heat is carried away will be less than the rate of heat release, and the difference will be stored in the metal of the riser tubes leading to their overheating and ultimately rupturing when the tube temperature exceeds the melting point of the metal.

If both down comers and risers are placed inside the furnace and heated, the density difference will be less. However, **for pressures less than 30 bar, both are placed inside with riser installed in the hotter zone**. The tubes which are heated more will act as risers and the tubes which are heated less act as **down comers**.

⇒ **Circulation ratio:**

$$C.R. = \frac{\text{Flow rate of saturated water in down comers}}{\text{Flow rate of steam released from the drum}}$$

⇒

$$C.R. = \frac{m}{m_g} = \frac{m_g + m_l}{m_g} = \frac{1}{m_g/(m_g + m_l)} = \frac{1}{TDF}$$

where, m = Mass of saturated water flowing through the downcomer riser circuit during a certain time.

m_g = Mass of steam released from the drum during same time.

$m_l = m - m_g$ = Mass of liquid (saturated) at the riser exit.

TDF = Top Dryness Fraction i.e., the quality of liquid vapour mixture discharged from riser into the drum.

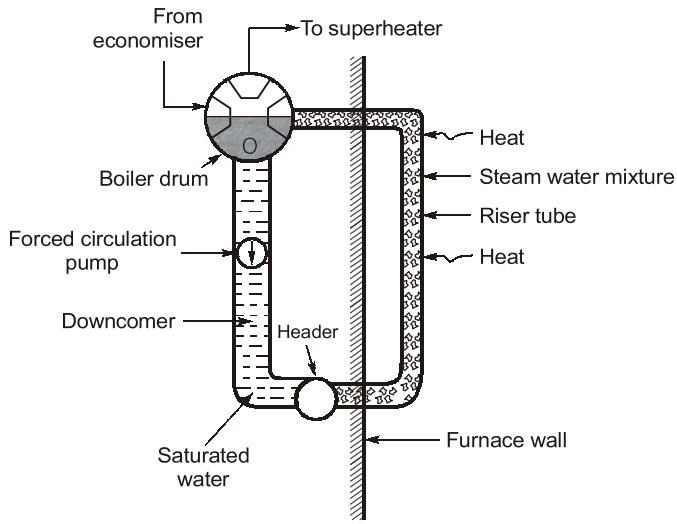


Figure: Forced circulation system

The circulation ratio in a natural circulation boiler varies from one riser tube to another. The riser tube located opposite to the burners have more thermal loading and generate more steam. So, these will have less circulation ratio. While the riser located in the corners of the furnace are relatively cooler, and so these will have more circulation ratio. However, the **circulation ratio in any tube should not be less than 6**, otherwise tube will get-overheated and fail prematurely and **not be higher than 25** for effective utilization of the tube in steam generator.

⇒ **Downcomers:**

- Downcomers are fewer in number and bigger in diameter and risers are more in number and smaller in diameter.
- In downcomers, water fall by gravity. Bigger the diameter, less the pressure drop due to friction, since

$$\text{Pressure drop} \propto \frac{1}{\text{Tube diameter}}$$

$$\Rightarrow \quad \Delta p \propto \frac{1}{D}$$

$$\because \quad \Delta p = \frac{f\rho V^2 L}{2D} = \frac{fL}{D}\rho\frac{V^2}{2}$$

So downcomers are made bigger in diameter, which may vary from **150 to 200 mm** or even higher.

$$m_f = n\left(\frac{\pi}{4}D^2\right)\rho_f V$$

where, m_f = Mass flow rate of saturated water in the downcomers, (kg/s)

n = Number of tubes

D = Diameter of downcomer (m)

ρ_f = Density of saturated water at the boiler drum pressure, (kg/m^3)

V = Average velocity of water in downcomers (m/s)

⇒ **Risers:**

- Absorbs heat from the furnace for the same total cross-sectional area, the smaller the diameter, larger the surface area exposed to hot gas for heat transfer. Therefore, the risers are of smaller diameter **62.5 to 76.5 mm**, and larger in number compared to downcomers.
- ***Nucleate*** boiling should occur in each riser tube and film boiling is avoided.
- Too much steaming and less circulation ratio in riser may cause **departure from nucleate boiling (DNB)** and onset of film boiling.
- To retard the onset of DNB, **internal twisters** and **springs** are provided which break the vapour film. Tubes ribbed helically on their inside surface are often used now.

⇒ **Slip Ratio (S):**

- When two-phase mixture is moving, the vapour, because of its buoyancy, has a tendency to slip past the liquid i.e. move at a higher velocity than a liquid.
  The slip ratio is defined as,

$$S = \frac{V_g}{V_l} = \frac{\text{Velocity of vapour}}{\text{Velocity of liquid}}$$

Slip ratio is varies between 1 and 10, approaching 1 at higher pressure (where the liquid and vapour densities approach each other). As pressure increases, the slip ratio decreases.

⇒ **Void Fraction (α):** The void fraction (α) of a two phase mixture, often called volumetric quality is defined as

$$\alpha = \frac{\text{Volume of vapour}}{\text{Volume of liquid + Volume of vapour}}$$

1.17.3 Steam Temperature Control

An accurate control of superheat temperature is important for efficient power plant operation. The principal variables affecting superheat temperature are:

1. Furnace temperature
2. Cleanliness of radiant and pendant superheaters.
3. Temperature of gases entering the convective superheater.
4. Cleanliness of convective superheater.
5. Mass flow rate of gases through the convective superheater.
6. Feedwater temperature
7. Variation of load on the unit.

These variables are not unrelated but the inter relationships among them are not simple. The last one, i.e. the effect of load variation on superheat temperature is, however, the most important.

The temperature of the saturated steam leaving the drum corresponds to the boiler pressure remains constant if the steam pressure controls are in working order. It is the superheater response to load changes which need to be corrected. There are several ways of doing this as given below:

1. Combined radiant-convective superheaters.
2. Desuperheating and attemperation.
3. Gas by-pass or damper control
4. Gas recirculation
5. Excess air
6. Tilting burners
7. Burner selection
8. Separately fired super heater.

■■■■

IMPORTANT POINTS TO REMEMBER

- A 'boiler is defined as a closed vessel in which steam is produced from water by combustion of fuel.
- **Example of fire tube boilers:** Cochran, Lancashire and Locomotive boilers, etc.
- **Example of water tube boilers:** Babcock and Wilcox, Stirling, Yarrow boiler, etc.
- Boiler mountings are different fittings and devices which are necessary for operation and safety of a boiler. **Example:** pressure gauge, safety valves, water level indicator, steam stop valve, feed check valve, blow-off cock, etc.
- Boiler accessories are auxiliary parts required for steam boilers for their proper operation and for the increase of their efficiency.
- The boiler draught may be defined as a small pressure difference which causes the flow of gases inside the boiler.
- An artificial draught produced by a fan or a blower is known as mechanical draught and that produced by a steam jet is known as a steam jet draught. In the induced draught system, the fan is placed near the base of the chimney. While in the forced draught, the fan or blower is located before the pre-heater.
- The draught obtained by use of a chimney is called natural or chimney draught. But the static draught produced by the chimney is not sufficient to meet the requirement of the draught of a boiler. Most commonly, the artificial draught is used on the boilers. The waste heat carried by the flue gases can better be utilized in a economiser, air preheater, etc. with the help of artificial draught.

OBJECTIVE BRAIN TEASERS

Q.1 The correct gas flow path in a typical large modern natural circulation boiler is
(a) Combustion chamber, Reheater, Superheater, Economiser, Air preheater, I.D. fan, Electrostatic precipitator, Stack
(b) Combustion chamber, Superheater, Reheater, Economiser, Air preheater, Electrostatic precipitator, I.D. fan, Stack
(c) Combustion chamber, Reheater, Superheater, Air preheater, Economiser, Electrostatic precipitator, I.D. fan, Stack
(d) Combustion chamber, Superheater, Reheater, Economiser, Air preheater, I.D. fan, Electrostatic precipitator, Stack

Q.2 Consider the following statements regarding a fluidized bed boiler
1. There is less formation of NO_x.
2. It can burn inferior grades of coal.
3. Furnace is compact
Which of these statements is/are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

Q.3 The excess air required for combustion of pulverized coal is of the order of
(a) 100 to 150% (b) 30 to 60%
(c) 15 to 40% (d) 5 to 10%

Q.4 Match **List-I** with **List-II** select the correct answer using the codes given below the lists:

List-I
A. Soot blower
B. Electrostatic precipitator
C. Blow down
D. Zeolite

List-II
1. Removal of solids from boiler drums
2. To clean the tube surfaces of fly ash
3. Cleaning of flue gases
4. Air cleaning
5. Water purification

Codes:

	A	B	C	D
(a)	2	4	3	5
(b)	1	3	2	5
(c)	3	2	1	4
(d)	2	3	1	5

Q.5 For which of the following type of combustion systems in boilers, superficial velocity is maximum?
(a) CFB boilers
(b) Pulverized coal firing systems
(c) Bubbling fluidised bed boilers
(d) Fixed bed boilers

Q.6 Consider the following components:
1. Radiation evaporator.
2. Economisers.
3. Radiation superheater.
4. Convection superheater.
In the case of Benson boiler, the correct sequence of the entry of water through these components is
(a) 1, 2, 3, 4 (b) 1, 2, 4, 3
(c) 2, 1, 3, 4 (d) 2, 1, 4, 3

Q.7 Which of the following form part(s) of boiler mountings?
(a) Economiser (b) Feed check valve
(c) Steam trap (d) Superheater

Q.8 Which one of the following safety devices is used to protect the boiler when the water level falls below a minimum level?
(a) Water level indicator
(b) Fusible plug
(c) Blow off cock
(d) Safety valve

Q.9 Match **List-I** (Boiler type) with **List-II** (Air velocity 'U') and select the correct answer using the codes given below the lists:
[U_t: Terminal velocity, U_{mf}: Minimum fluidization velocity]

List-I
A. Bubbling fluidised bed
B. Circulating fluidised bed
C. Fixed Bed Boiler

List-II

1. $U > U_t$
2. $U_t > U > U_{mf}$
3. $U_{mf} > U$

Codes:

	A	B	C
(a)	1	3	2
(b)	2	3	1
(c)	1	2	3
(d)	2	1	3

Q.10 Which of the following is an internally fired fire-tube boiler?
(a) Locomotive boiler
(b) Lancashire boiler
(c) Scotch-marine boiler
(d) La-Mont boiler [MSQ]

Q.11 Which of the following is a boiler mounting?
(a) Steam trap (b) Feed pump
(c) Economiser (d) Safety valve

Q.12 Consider the following factors :
1. Floor area required.
2. Working pressure and amount of steam needed.
3. Amount of fuel required.
4. Water requirements.

Which of the factors given above should be considered for selecting a boiler in a steam power plant?
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2, 3 and 4

Q.13 Consider the following:
1. Safety valve 2. Fusible plug
3. Economiser 4. Pressure gauge

The essential boiler mountings would include
(a) 1, 3 and 4 (b) 3 and 4
(c) 1, 2 and 3 (d) 1, 2 and 4

Q.14 In a power plant, the efficiencies of the electric generator, turbine, boiler, air standard cycle and overall plant are 0.94, 0.97, 0.92, 0.42 and 0.32 respectively. The percentage of the total electricity generated consumed in running the auxiliaries is
(a) 7.32 (b) 6.34
(c) 9.17 (d) 8.75

Q.15 Consider the following statements regarding blow- off cock:
1. Blow-off cock is used to extinguish fire in the furnace when water level falls.
2. It is installed at the bottom of the boiler of drum near its end.

Which of the above statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

Q.16 A forced draught fan delivers the air to the air preheater at a pressure of 1 bar and a temperature of 27°C with a pressure rise across the fan of 180 mm of water. The power input to the fan is 5 kW and it has a mechanical efficiency of 90%. The mass flow rate of air will be
(a) 1.7 kg/sec (b) 2.95 kg/sec
(c) 4.2 kg/sec (d) 6.45 kg/sec

Q.17 Consider the following statements regarding the function of draught system in boiler furnace:
1. To supply the required quantity of air for complete combustion of fuel to the furnace.
2. To remove the gaseous products of combustion from the furnace and throw these to chimney or stack to the atmosphere.

Which of the above statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) None of these

Q.18 A furnace wall riser 20 m long receives saturated water having density of 750 kg/m^3 at 80 bar. If the density of liquid vapour mixture at top of riser is 320 kg/m^3, the pressure head developed will be
(a) 32.72 kPa (b) 24.52 kPa
(c) 56.24 kPa (d) 42.18 kPa

Q.19 Lancashire boilers are
(a) Internally fired water tube boilers
(b) Externally fired water tube boilers
(c) Internally fired fire tube boilers
(d) Externally fired fire tube boilers

Q.20 A thermal power plant utilizes 240 kg of coal (H.V. = 32 MJ/kg) per minute. The steam generator has an efficiency of 70% and the net turbine heat rate is 2.5. The net turbine output of the power plant is

(a) 42.6 MW (b) 35.8 MW
(c) 31.8 MW (d) 39.4 MW

Q.21 Which of the following statements is not correct regarding the circulation in boilers?

(a) Downcomers are placed inside the furnace for low pressure boilers.
(b) Natural circulation is effective in high pressure boilers.
(c) Once-through boilers do not require a boiler drum.
(d) There will be no natural circulation at the critical pressure.

Direction (Q.22 to Q.23): The following items consists of two statements, one labelled as **Statement (I)** and the other labelled as **Statement (II)**. You have to examine these two statements carefully and select your answers to these items using the codes given below:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

Q.22 **Statement (I):** Fire tube boilers can meet relatively large and sudden load demands with only small pressure changes.
Statement (II): Water tube boilers cannot withstand extreme pressures of modern steam generator.

Q.23 **Statement (I):** Circulation ratio of boiler should be as high as possible.
Statement (II): Riser tube may fail prematurely if circulation ratio is very low.

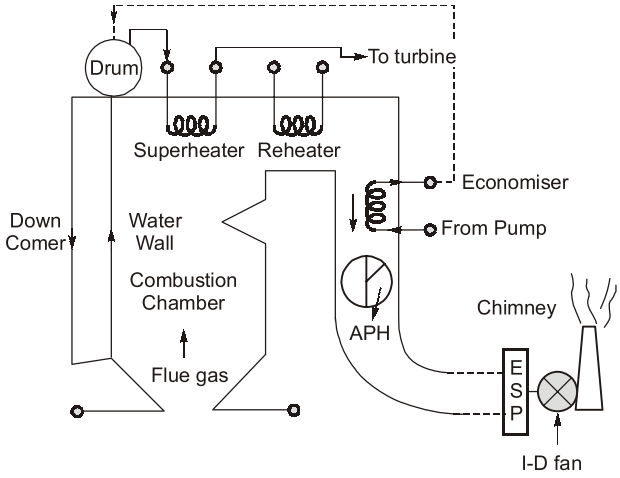
■■■■

ANSWER KEY

1. (b)	2. (d)	3. (c)	4. (d)	5. (b)
6. (d)	7. (b)	8. (b)	9. (d)	10. (b,c)
11. (d)	12. (d)	13. (d)	14. (c)	15. (b)
16. (b)	17. (c)	18. (d)	19. (c)	20. (b)
21. (b)	22. (c)	23. (d)		

HINTS & EXPLANATIONS

1. (b)



2. (d)

Advantages of fluidized bed boiler:

1. Any cheap fuel without the support of any auxiliary fuel can be used.
2. Due to superior mixing of solid fuels with air combustion efficiency is very high (up to 99%).
3. Due to low combustion temperature (around 900°C) and the staged combustion process, NO_x emission is very low.
4. Compact furnace.

3. (c)

Fuel	Excess Air (%)
Anthracite	40%
Coal, Pulverized	15-20%
Coal, Stoker	20-30%
Semi-anthracite with travelling cirate	30-60%

4. (d)

Soot blower: To clean the tube surfaces of fly ash

Electrostatic precipitator: Cleaning of flue gases by collecting fly ash particles

Blow down: Removes solid precipitates from boiler drums

Zeolite: Feed water purification

6. (d)

(i) Feed pump feeds water to the economiser

(ii) Most of the heat is transmitted and water gets heated in the radiation evaporator.

(iii) Then, superheating is done by convection superheater followed by radiation superheater.

7. (b)

The equipment used for safe working of the boiler are known as mountings. Following is the list of mountings which are normally used on the boiler.

(a) For control of water and steam valve
   1. Feed check valve 2. Steam stop valve

(b) For safety of boiler
   1. Pressure gauge
   2. Water level indicator
   3. Safety valve
   4. Fusible plug

(c) For cleaning and maintenance purpose
   1. Man hole

Boiler accessories are provided to improve the efficiency of the plant.

The commonly used accessories are:

1. Superheater 2. Economiser
3. Air preheater 4. Feed pump
5. Steam separator

8. (b)

The function of a fusible plug is to extinguish the fire of the furnace when the water level inside the boiler falls to a dangerously low level. If this is not done the boiler tubes and shell may be damaged due to overheating or the boiler may explode.

9. (d)

Fixed bed : Low gas velocity

Bubbling fluidised bed : Turbulent fluidization

$$U_t > U > U_{mf}$$

Circulating fluidised Bed : Fast fluidization

$$U > U_t$$

12. (d)

Following are the factors on which selection of boiler is done:

1. Working pressure and amount of steam needed.
2. Floor area required.
3. Operating and maintenance required.
4. Amount of fuel required.
5. Water requirements.
6. Type of load-safety fluctuations etc.

13. (d)

Various boiler mountings are as under

1. Pressure gauge
2. Water level indicator
3. Fusible plug
4. Safety valve
5. Steam stop valve
6. Feed check valve
7. Blow off cock

14. (c)

$$\eta_{plant} = \eta_{boiler} \times \eta_{turbine} \times \eta_{generator} \times \eta_{cycle} \times \eta_{auxiliaries}$$

$$\therefore \quad \eta_{auxiliaries} = \frac{0.32}{0.94 \times 0.97 \times 0.92 \times 0.42}$$

$$= 0.9082$$

$$\therefore \% \text{ electricity consumed} = (1 - \eta_{auxiliaries}) \times 100$$

$$= (1 - 0.9082) \times 100 = 9.17\%$$

15. (b)

- Blow off cock is used to remove heavy impurities settled at the bottom of boiler drum.
- It is installed at the bottom of the boiler of drum near its end.

16. (b)

Power input to the FD fan,

$$P = \frac{\dot{V} \times \Delta P}{\eta_{mech}}$$

$$\Rightarrow \quad \dot{V} = \frac{P \times \eta_{mech}}{\rho_w g h}$$

$$\therefore \dot{V} = \frac{5 \times 10^3 \times 0.9}{10^3 \times 9.81 \times 0.18} = 2.54 \text{ m}^3/\text{sec}$$

Density of air,

$$\rho_a = \frac{P_1}{RT_1} = \frac{1 \times 10^5}{287 \times 300} = 1.16 \text{ kg/m}^3$$

∴Mass flow rate of air,

$$\dot{m}_a = \rho_a \times \dot{V}$$

$$\dot{m}_a = 1.16 \times 2.54$$

$$\dot{m}_a = 2.95 \text{ kg/sec}$$

18. (d)

As per given data,

$\rho_f = 750 \text{ kg/m}^3$, $\rho_{top} = 320 \text{ kg/m}^3$

∴ Average density of liquid vapour mixture in the riser tube,

$$\rho_m = \frac{\rho_f + \rho_{top}}{2}$$

$$= \frac{750 + 320}{2} = 535 \text{ kg/m}^3$$

$$\therefore \quad \Delta P = gH\left(\rho_f - \rho_m\right)$$

$$\Delta P = 9.81 \times 20 \times (750 - 535)$$

$$\Delta P = 42.18 \text{ kPa}$$

20. (b)

$$\text{NTHR} = \frac{\eta_B \times \dot{m}_f \times H.V.}{NTO}$$

$$\text{NTO} = \frac{0.7 \times \frac{240}{60} \times 32}{2.5} = \frac{7 \times 4 \times 32}{25}$$

$$= 35.84 \text{ MW}$$

21. (b)

Density difference decreases as the boiler pressure increases. So, high pressure boilers require forced circulation.

22. (c)

Water tube boilers are capable of withstanding extreme pressures of modern steam generators.

23. (d)

Very low circulation ratio causes overheating and failure of riser tubes while C.R. should not be too much high for proper utilisation of tube.

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CONVENTIONAL BRAIN TEASERS

Q.1 Following are the details of a working boiler:

Pressure of steam = 10 bar, Quality of steam = 0.9 dry
Quantity of steam = 5500 kg/h, Temperature of feed water = 37°C
Coal consumption = 700 kg/h, Calorific value of coal = 30 MJ/kg

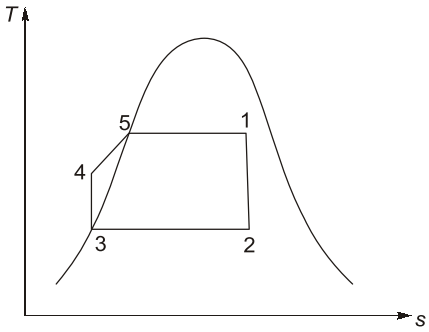
What would be saving in coal consumption per hour if by putting an economiser the temperature of feed water is raised to 100°C and other data remains the same except that the boiler efficiency increased by 6%? Neglect the pump work. At 10 bar; h_f = 750 kJ/kg, h_{fg} = 2050 kJ/kg.

Temperature based saturation steam table:

°C	P_S(kPa)	h_f(kJ/kg)	h_{fg}(kJ/kg)
35	5.63	145	2420
40	7.40	165	2400
100	101.5	420	2250

Solution:

Given : $P_1 = P_5 = P_4$ = 10 bar; T_4 = 37°C, x_1 = 0.9, $\dot{m}_s$ = 5500 kg/h; $\dot{m}_f$ = 700 kg/h; C.V. = 30 MJ/kg



Increment in boiler efficiency = 6%

At 10 bar,

$$h_5 = h_f = 750 \text{ kJ/kg}$$

$$h_{fg} = 2050 \text{ kJ/kg}$$

$$\therefore \quad h_1 = h_f + xh_{fg} = 750 + 0.9 \times (2050)$$

$$= 2595 \text{ kJ/kg}$$

$$(h_w)_{35°C} = 145 \text{ kJ/kg}$$

$$(h_w)_{40°C} = 165 \text{ kJ/kg}$$

By linear interpolation,

$$(h_w)_{37°C} = 153 \text{ kJ/kg}$$

Now, Efficiency of boiler, $\eta = \dfrac{\dot{m}_s \times (h_1 - h_w)}{\dot{m}_f \times C.V.}$; $\quad (h_w = (h_w)_{37°C})$

$$= \frac{5500 \times (2595 - 153)}{700 \times 30 \times 1000} = 0.639 \simeq 0.64$$

$$\simeq 64\%$$

When economiser is used then,

$$\text{New efficiency, } \eta' = (64 + 6)\% = 70\%$$

$$\therefore \quad \eta' = \frac{\dot{m}_s \times (h_1 - h_w)}{\dot{m}_f \times C.V.}; \qquad (h_w = (h_w)_{100^\circ C})$$

$$0.7 = \frac{5000 \times (2595 - 420)}{\dot{m}_f \times 30 \times 1000}$$

$$\Rightarrow \quad \dot{m}_f = 569.64 \text{ kg/hr}$$

$$\therefore \quad \text{Saving in coal consumption per hour} = (700 - 569.64) \text{ kg/hr}$$

$$= 130.357 \text{ kg/hr}$$

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