Basic Mechanical Engineering (3110006)

Chapter 6 Steam Boilers

Outline

6.1	Steam boilers Introduction	
6.2	Classification of steam boiler	
6.3	Cochron Boiler	
6.4	Lancashire Boiler	
6.5	Babcock – Wilcox Boiler	
6.6	Functioning of different mountings	
6.7	Functioning of different Accessories	

Steam Generators/Boilers

- "A combination of apparatus for producing, furnishing or recovering heat together with apparatus for transferring the heat so made available to water which would be heated and vaporized to steam form" (ASME).

- Basis for classification of boilers
  - Contents inside the tube
  - Firing system
  - Position of drum
  - Pressure
  - Nature of water circulation

Formation of Steam at Constant Pressure

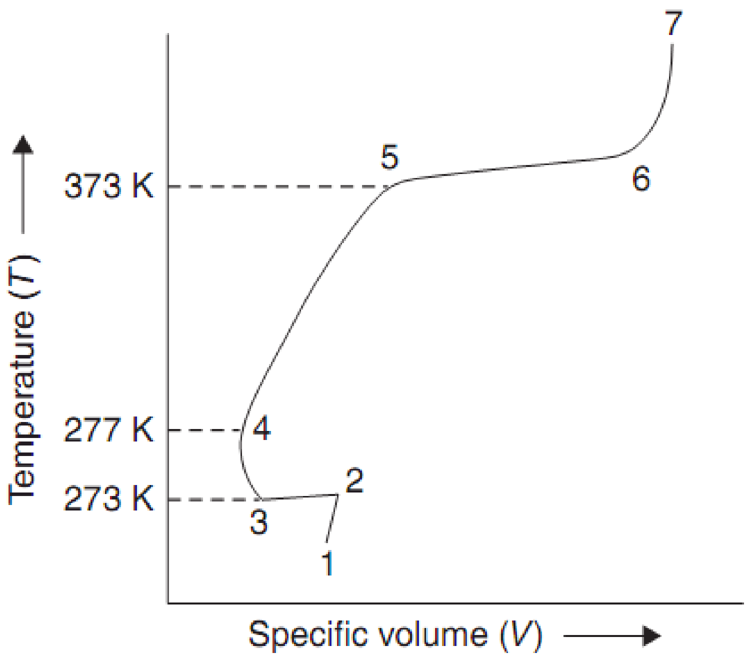


Figure 4.1 *T–V* Diagram for Various Phases of Wate

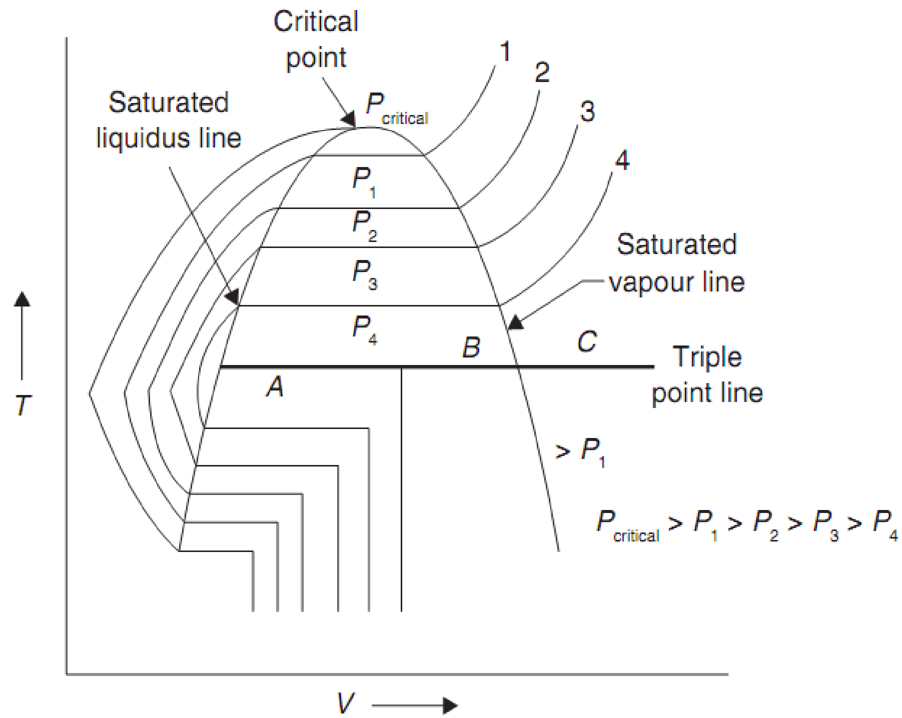


Figure 4.2 *T–V* Diagram at Different Pressures

$$P_c = 221.2 \text{ bar},\ T_c = 647.3°\text{C},\ V_c = 0.00317 \text{ m}^3/\text{kg}$$

P_{triple} = 0.006112 bar, T_{triple} =273.16°C

P–V Diagram, T–s Diagram, h–s Diagram and P–s Diagram

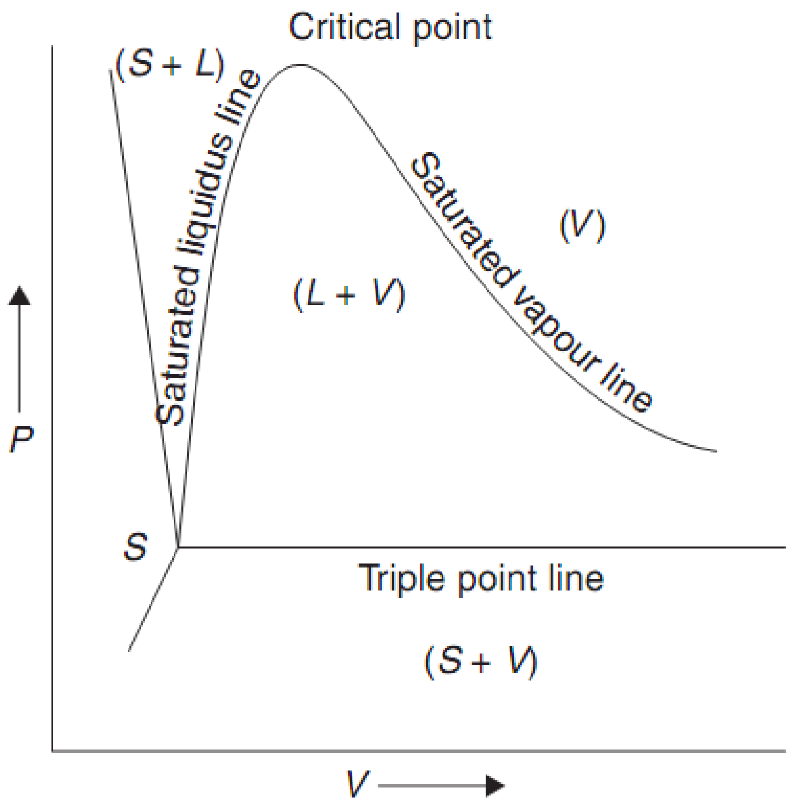


Figure 4.3(a) *P–V* Diagram

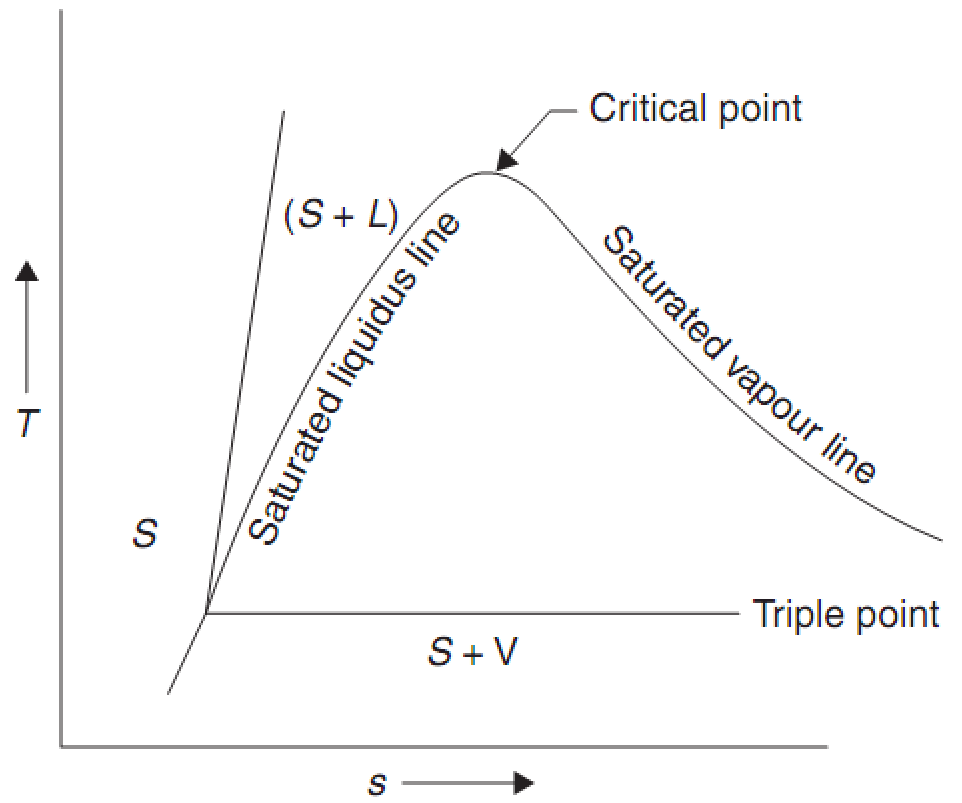


Figure 4.3(b) *T–s* Diagram

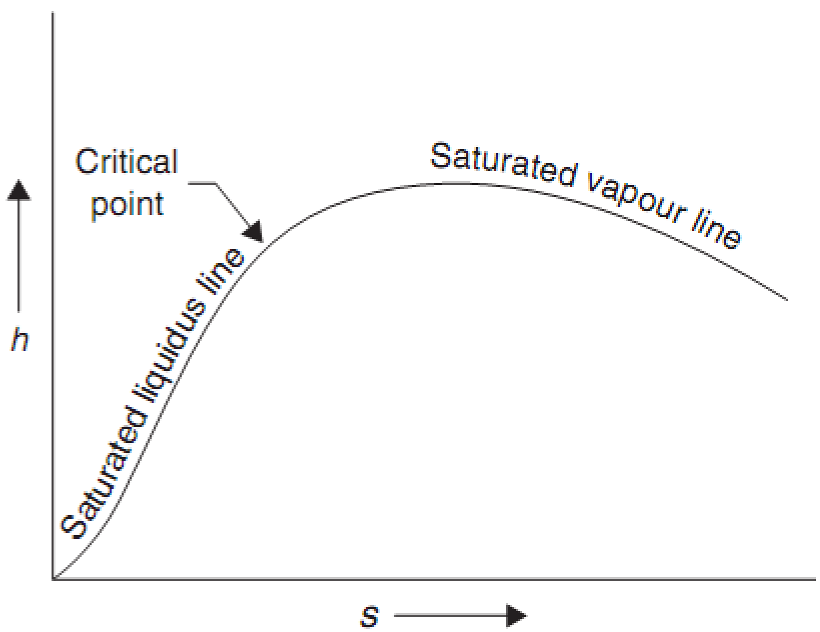


Figure 4.3(c) *h–s* Diagram

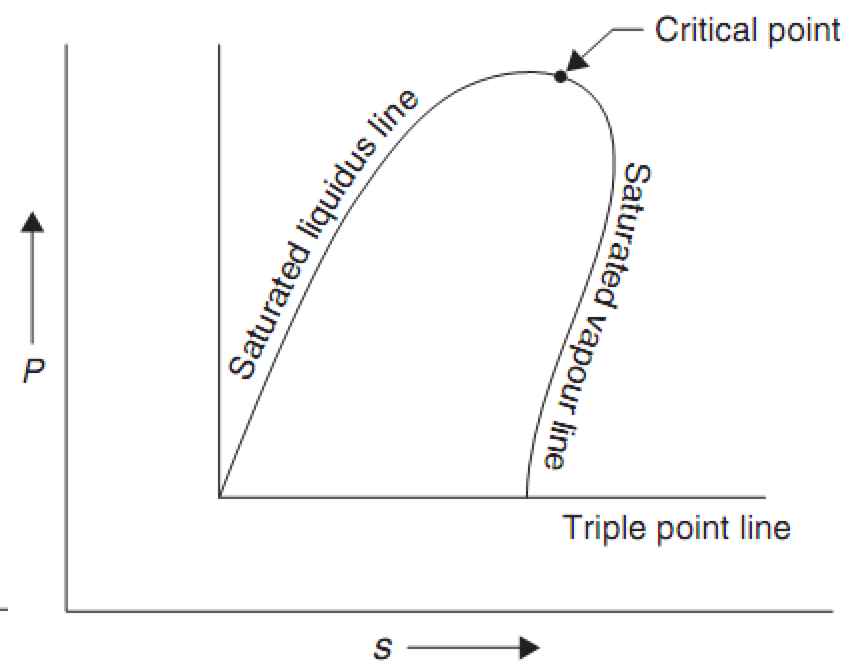


Figure 4.3(d) *P–s* Diagram

Steam Generation

- Enthalpy Change in Generation of Steam from 0°C at 0°C

$$h_0 = u_0 + PV_0; \text{ at } 0°\text{C}, u_0 = 0$$

$$h_0 = PV_0; \qquad \text{where } V_0 \text{ is specific volume at } 0°\text{C}.$$

- 0°C to Saturation Temperature

$$h_f = u_f + PV_f \text{ where } V_f \text{ is specific volume at saturation temperature.}$$

$$h_0 = PV_0$$

$$h_f - h_0 = h = u_f + P(V_f - V_0)$$

•**Wet Steam**: Wet steam contains partly water as suspended in it and partly steam

- **Dryness Fraction**: Dryness fraction is defined as the mass of dry steam per kg of wet steam. It is represented by x.

$$x = \frac{m_g}{m_g + m_f}$$

- Enthalpy

$$h = xh_g + (1 - x)\, h_f = h_f + xh_{fg}$$

- Specific Volume

$$V = xV_g + (1 - x)\, V_f = V_f + xV_{fg}$$

- Internal Energy

$$u_f = h_f - P_f V_f$$

$$u_g = h_g - P_g V_g$$

- Entropy of Water

$$\Delta S = S_2 - S_1 = \int_{T_1}^{T_2} \frac{C_p\, dT}{T} = C_p \log_e \frac{T_2}{T_1}; \quad \text{at constant pressure}$$

- **Entropy of Steam**

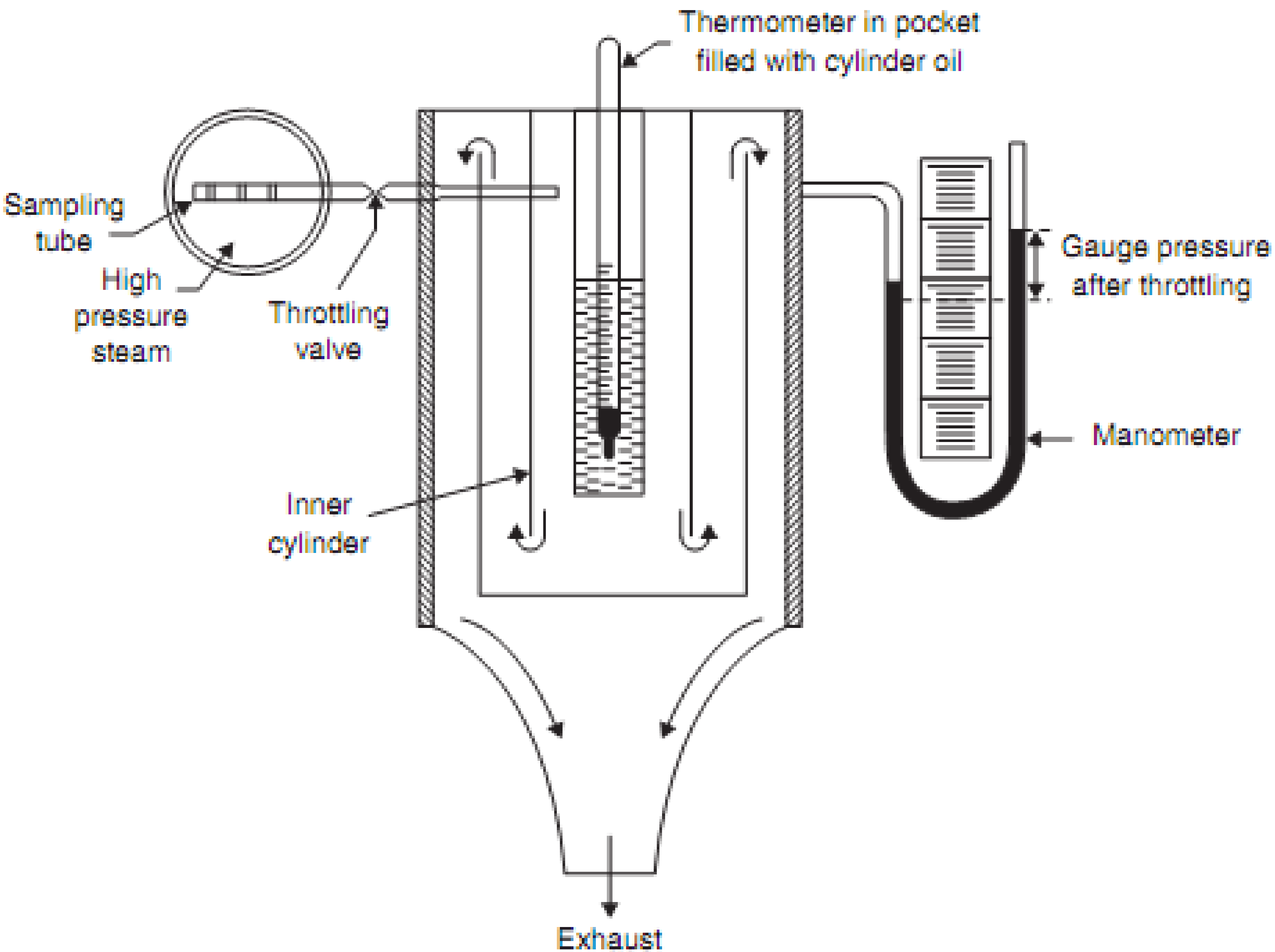
$$S = S_f + S_{fg} = C_p \log_e \frac{T_S}{T_0} + \frac{h_{fg}}{T_S} \text{ for dry saturated steam at constant pressure } (x = 1)$$

$$S = S_f + xS_{fg} = C_p \log_e \frac{T_S}{T_0} + \frac{xh_{fg}}{T_S} \text{ for wet steam at constant pressure}$$

$$S = S_f + xS_{fg} + S_g = C_{pw} \log_e \frac{T_S}{T_0} + \frac{xh_{fg}}{T_S} + C_p \log_e \frac{T_{Sup}}{T_S} \text{ for superheated steam at constant pressure}$$

where $C_{pw} \approx 1$, specific heat of water.

Throttling Calorimeter



$$x_1 = \frac{h_{g2} + C_p(t_{sup} - t_{S2}) - h_{f1}}{h_{fg}}, \text{ where } C_p = 0.48$$

P_1 = Initial pressure of steam

P_2 = Final pressure = Atmospheric pressure + Manometer reading

h_{f1} = Enthalpy of water at pressure, P_1

h_{fg1} = Enthalpy of vaporization at pressure, P_1

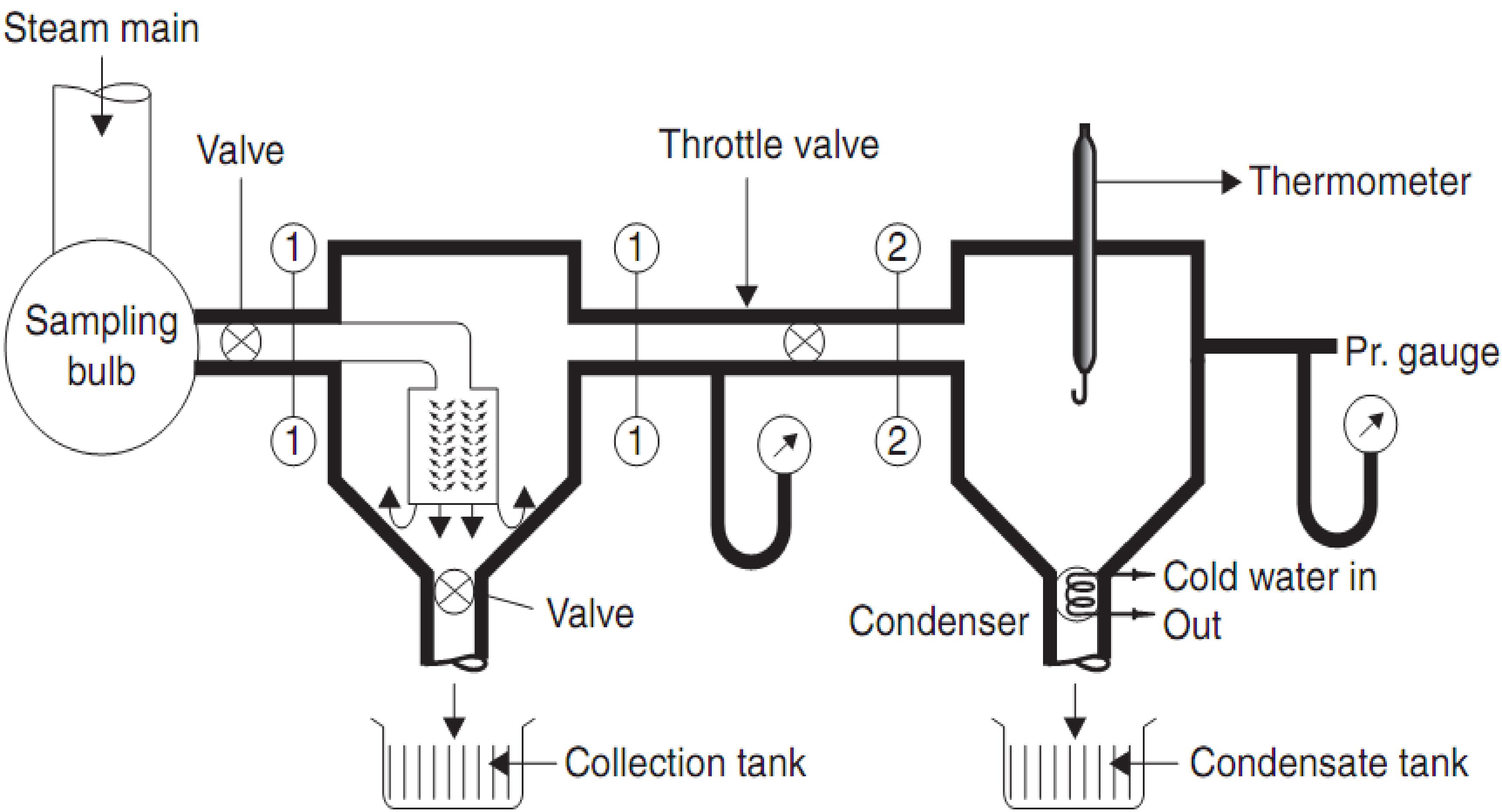
C_{pg} = Specific heat of superheated steam

t_{S2} = Saturation temperature at final pressure, P_2

t_{sup} = Temperature recorded by thermometer

x_1 = Dryness fraction of steam before throttling

Separating and Throttling Calorimeter



Let M = Mass of steam passing through throttling calorimeter

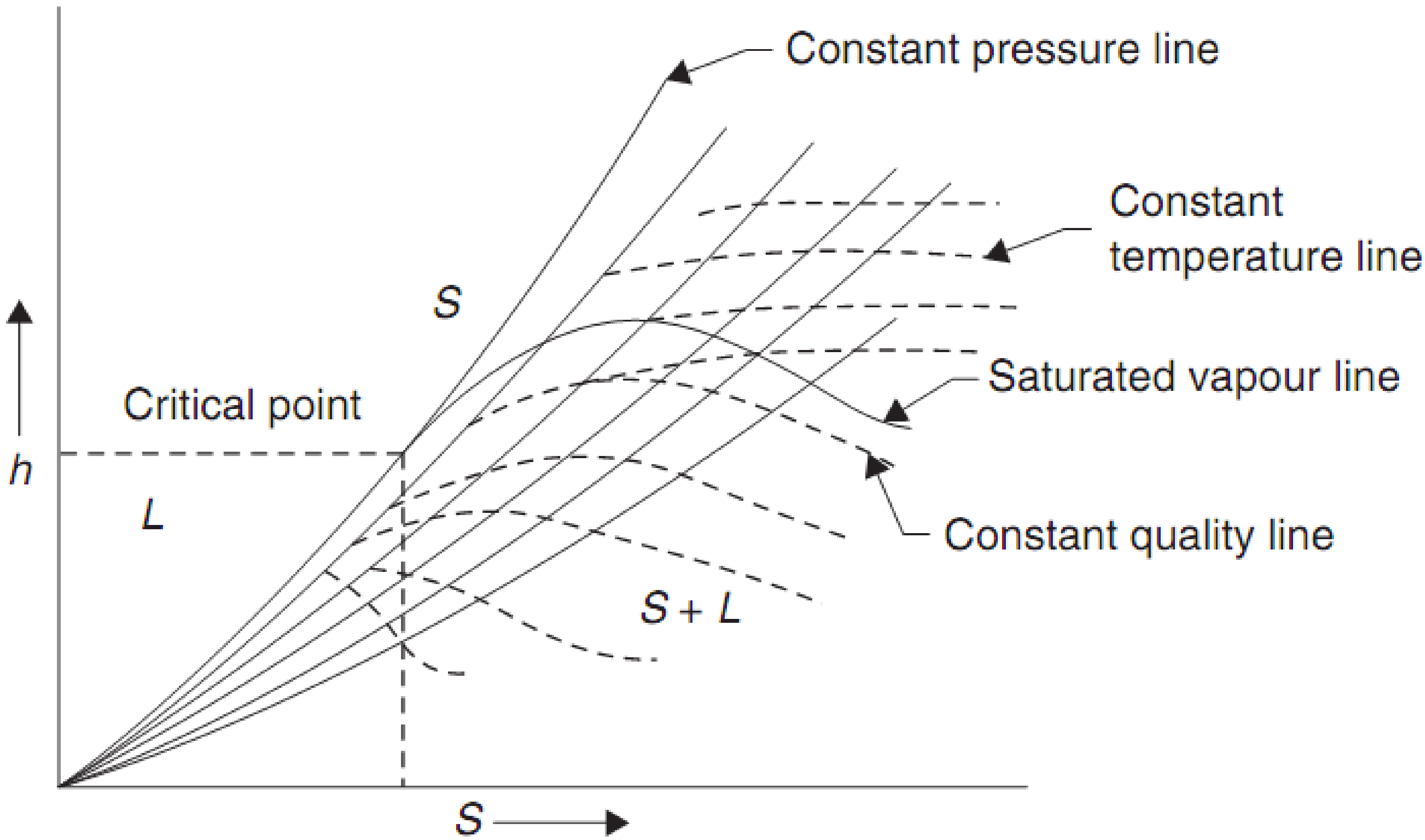
x_2 = The dryness fraction entering into the throttling calorimeter that is determined by throttling calorimeter

M = Mass of water separated out in separating calorimeter

x = Dryness fraction of steam entering the separating calorimeter

Thus, $x = \frac{M}{M+m} x_2$ or, $x = x_1 \times x_2$, where $x_1 = \frac{M}{M+m}$

Mollier Diagram or h–S Chart



Steam Generators/Boilers

- “A combination of apparatus for producing, furnishing or recovering heat together with apparatus for transferring the heat so made available to water which would be heated and vaporized to steam form” (ASME).

- Basis for classification of boilers
  - Contents inside the tube (water tube, Fire tube)
  - Firing system (Internal, External)
  - Position of drum (Horizontal, Vertical, Inclined)
  - Pressure (Low Up to 80 bar, High 80-221 bar, Super critical above 221 bar)
  - Nature of water circulation (Natural, Forced)

Water Tube and Fire Tube Boilers

Water tube boilers	Fir tube boilers
1. Water flows inside the tube.	1. Flue gas flows inside the tube.
2. It is more safer than fire tube boilers because a large part of the water is in smaller tubes which if rupture, only a comparatively small volume of water released into flash of steam.	2. It is more dangerous compared to water tube boiler.
3. It is more efficient and economic.	3. It is less efficient and non-economic.
4. Pressure limit in water tube boilers is much higher than the fire tube boilers.	4. Pressure limit is very low. It is approximately 16–20 bar.
5. Water tube boilers are most suitable for large sized boiler.	5. Fire tube boilers are most suitable for small sized boiler.
6. In this boiler, steam production rate is very high.	6. Steam production rate is low.
7. Water treatment plant is required due to problem of scaling inside the tube.	7. There is no need of water treatment plant.

Requirements of a Good Boiler

- Low cost of installation, operation and maintenance
- Easy maintenance
- High efficiency
- Safety
- High transportability
- High steam production rate
- Good quality of steam
- Quick steam generation capacity
- Meeting fluctuating demand of steam

Cochran Boiler

Components:

1. Hemispherical shell
2. Flue pipe
3. Combustion chamber
4. Smoke box
5. Chimney
6. Grate
7. Ash pit
8. Fire door
9. Furnace
10. Feed check valve
11. Pressure gauge
12. Water gage
13. Safety valve
14. Steam stop valve
15. Blow-off cock
16. Fusible plug

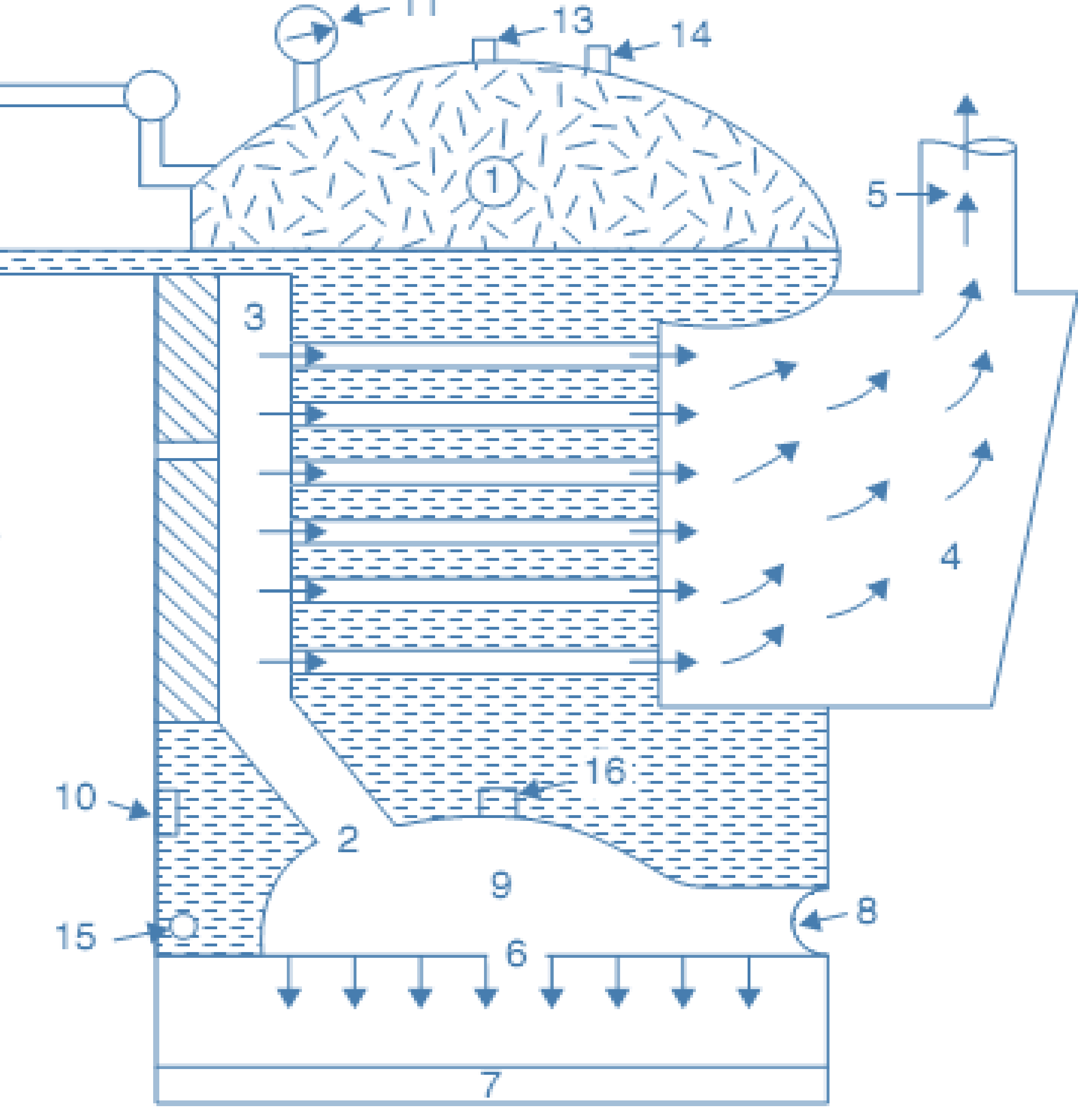


Figure 4.10 Cochran Boiler

Babcock and Wilcox Boiler

Components:

1. Drum
2. Pressure gauge
3. Water level indicator
4. Safety valve
5. Feed check valve
6. Man hole
7. Header
8. Down comers
9. Steam stop valve
10. Anti-priming pipe
11. Super heater
12. Baffles
13. Water tube
14. Fire grate
15. Fire door
16. Ash pit
17. Clean out door
18. Blow-off cock
19. Chimney
20. Damper

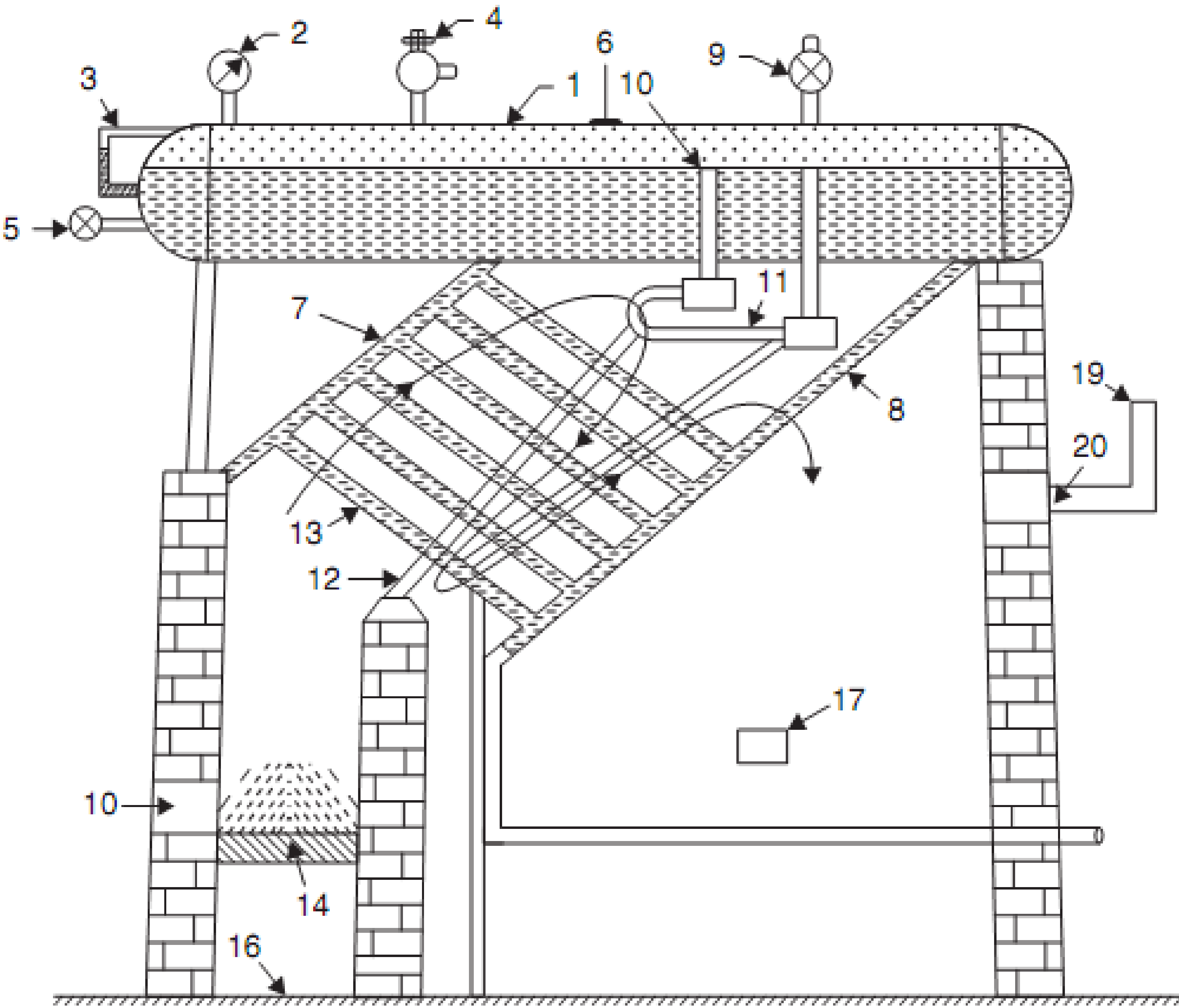
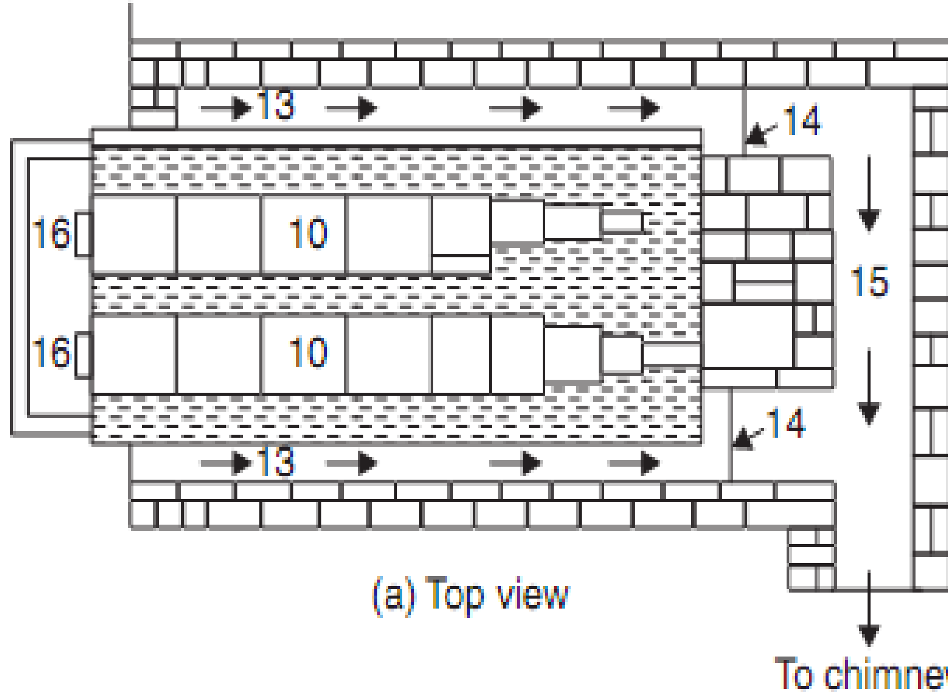


Figure 4.11 Babcock and Wilcox Boiler

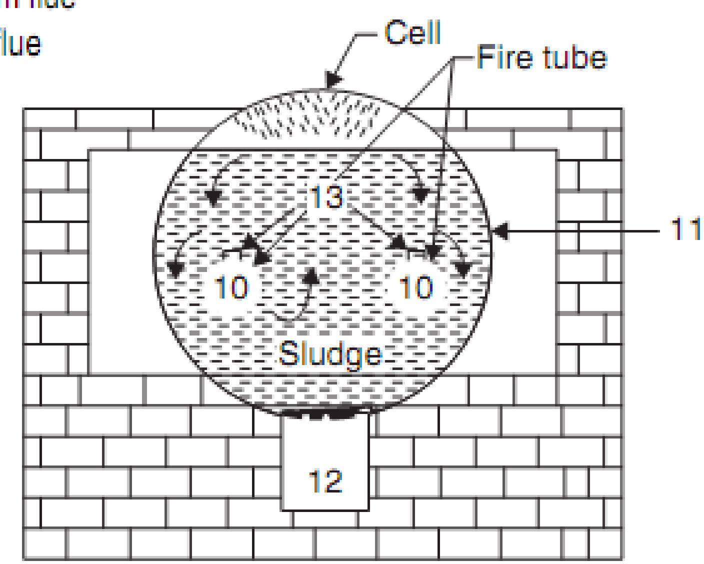
Lancashire Boiler

Components:

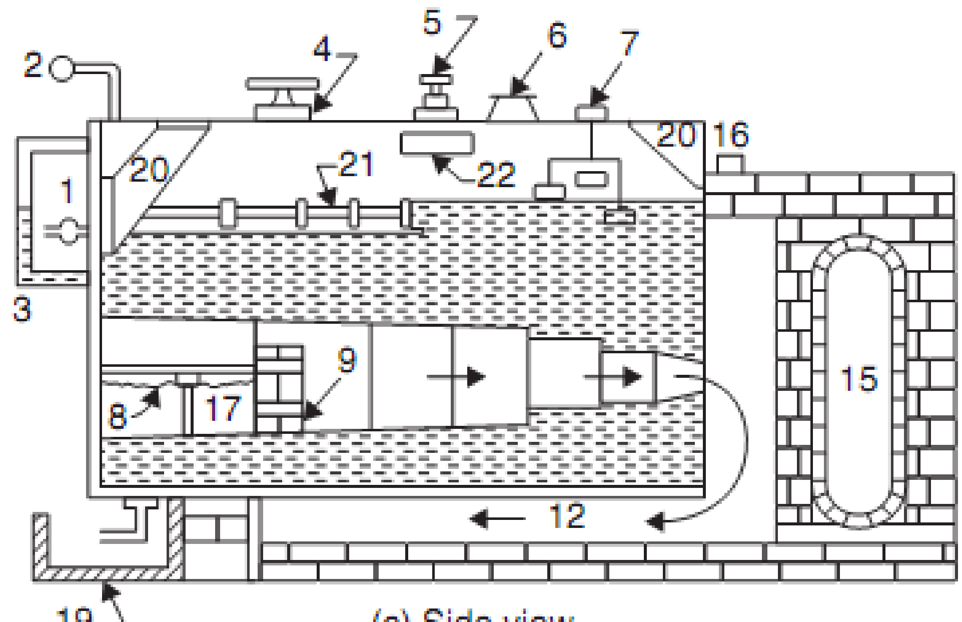
1. Feed check valve
2. Pressure gauge
3. Water level Indicator
4. Dead weight safety valve
5. Steam stop valve
6. Man hole
7. High steam low water safety valve
8. Fire grate
9. Fire bridge
10. Flue tubes
11. Boiler shell
12. Bottom flue
13. Side flue
14. Dampers
15. Man hole
16. Doors
17. Ash pit
18. Blow-off cock
19. Blow-off pit (for disposal of blow-off water)
20. Gusset stays
21. Perforated feed pipe
22. Anti-priming device
23. Fusible plug



(a) Top view

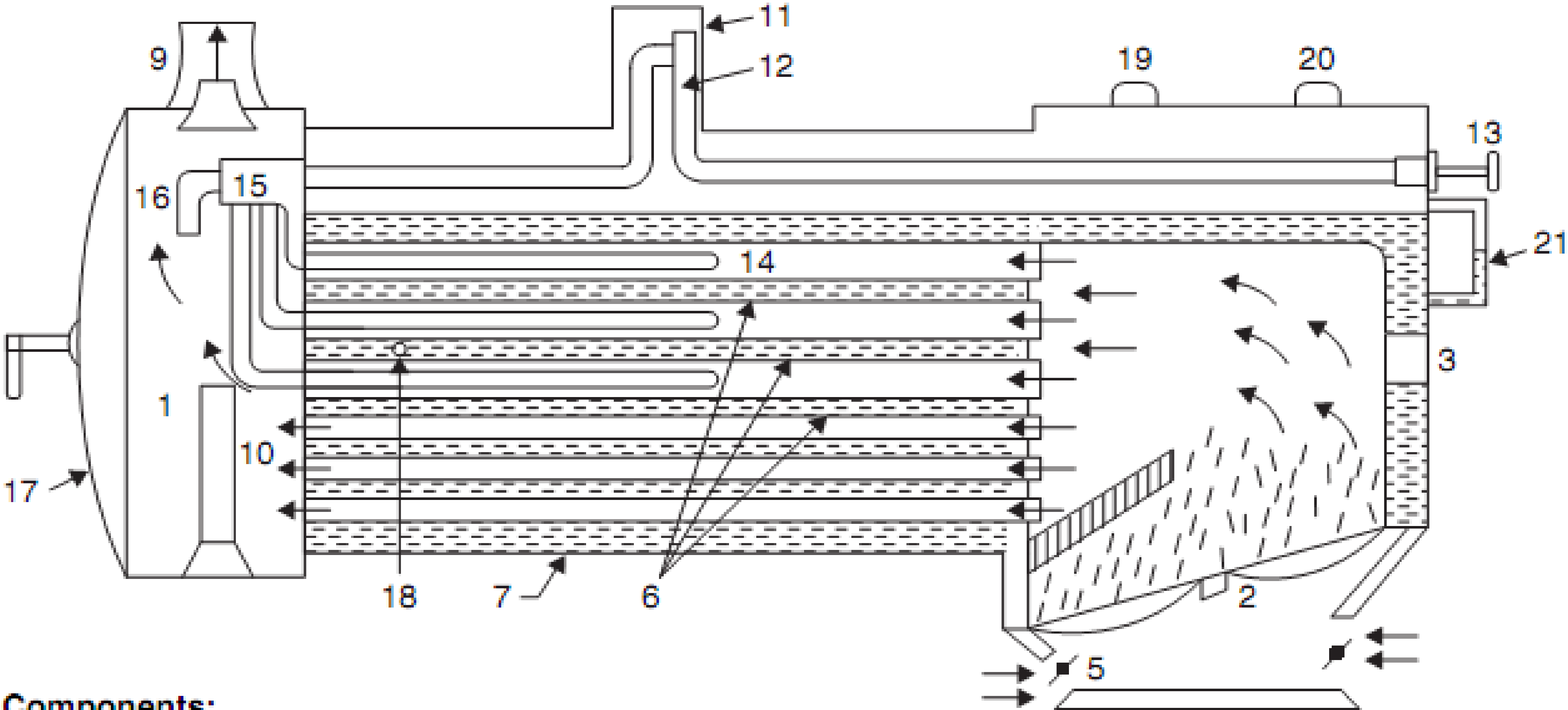


(b) Front view



(c) Side view

Locomotive Boiler



Components:

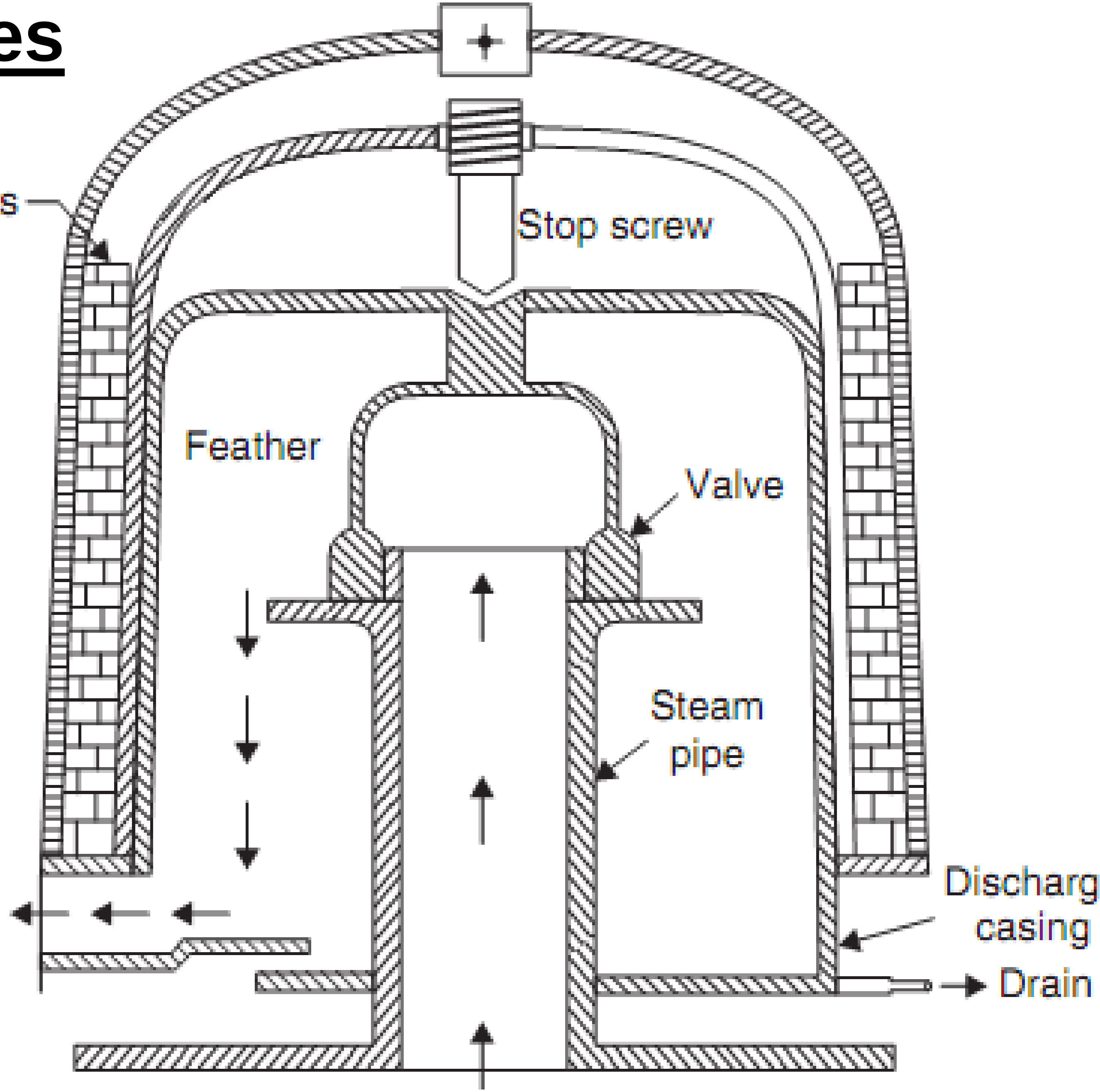
1. Fire box
2. Grate
3. Fire hole
4. Fire bridge arch
5. Ash pit
6. Fire tubes
7. Barrel (shell)
8. Smoke box
9. Chimney
10. Exhaust steam pipe
11. Steam dome
12. Regulator
13. Lever
14. Super heater tubes
15. Super heater header
16. Outlet pipe
17. Smoke box door
18. Feed check valve
19. Safety valve
20. Whistle
21. Water gauge

Figure 4.12 Locomotive Boiler

Boiler Mountings

- Safety valve
- Water level indicator
- Pressure gauge
- Fusible plug
- Steam stop valve
- Feed check valve
- Blow-off cock
- Man and mud hole

Safety Valves



1) Dead Weight Safety Valve

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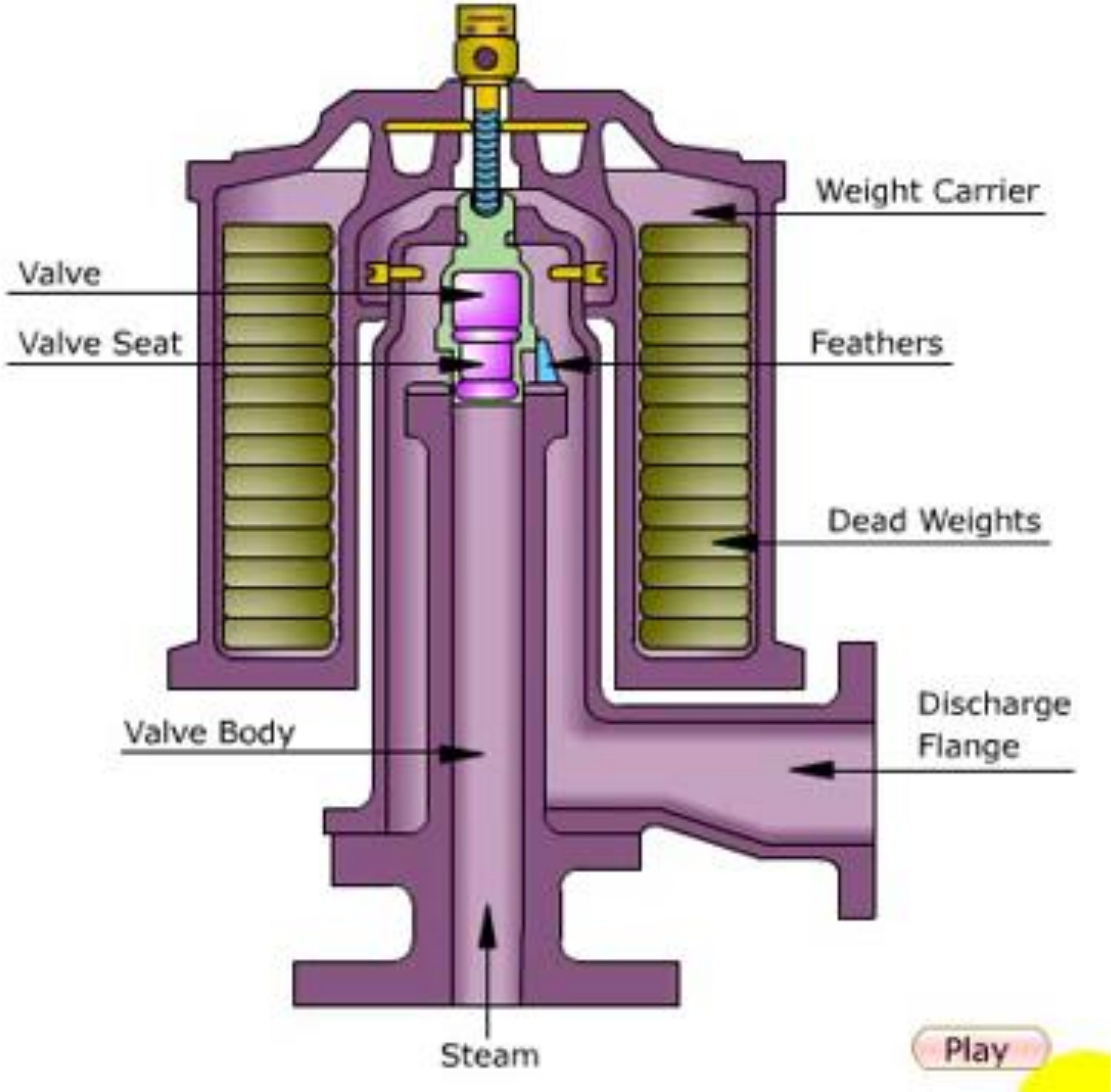
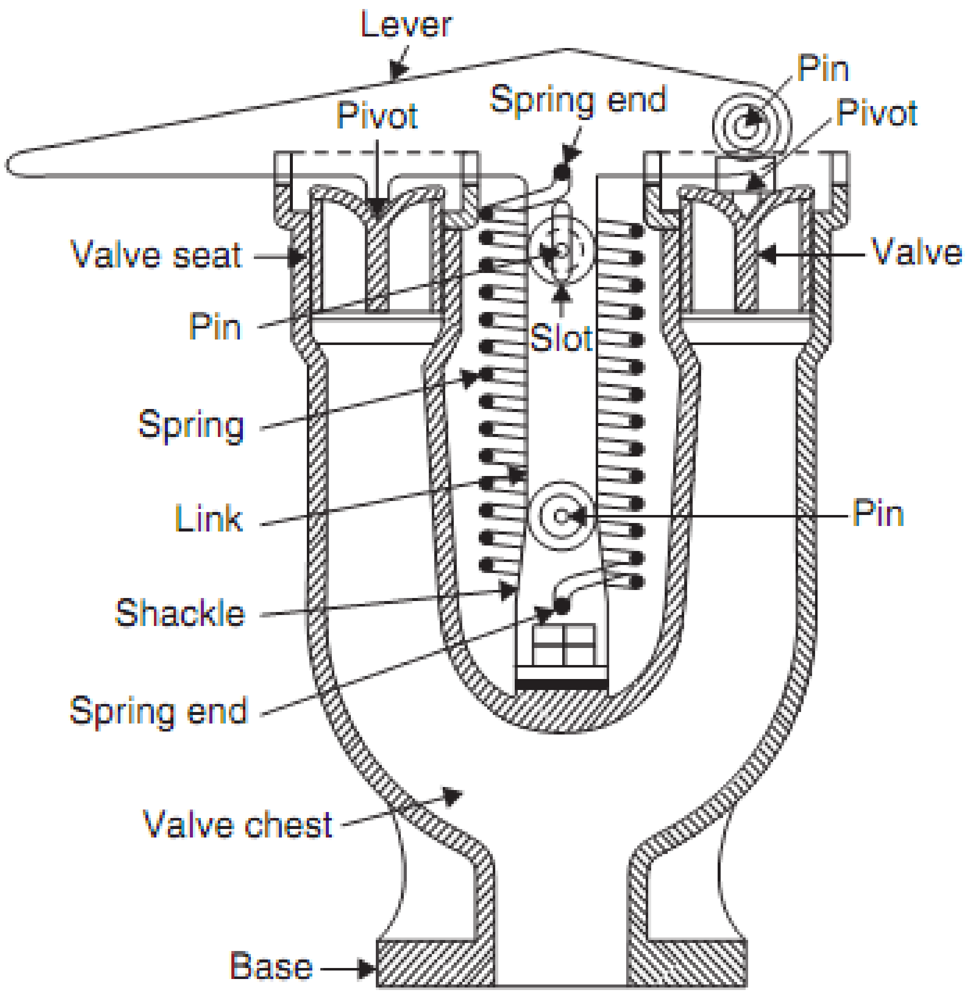
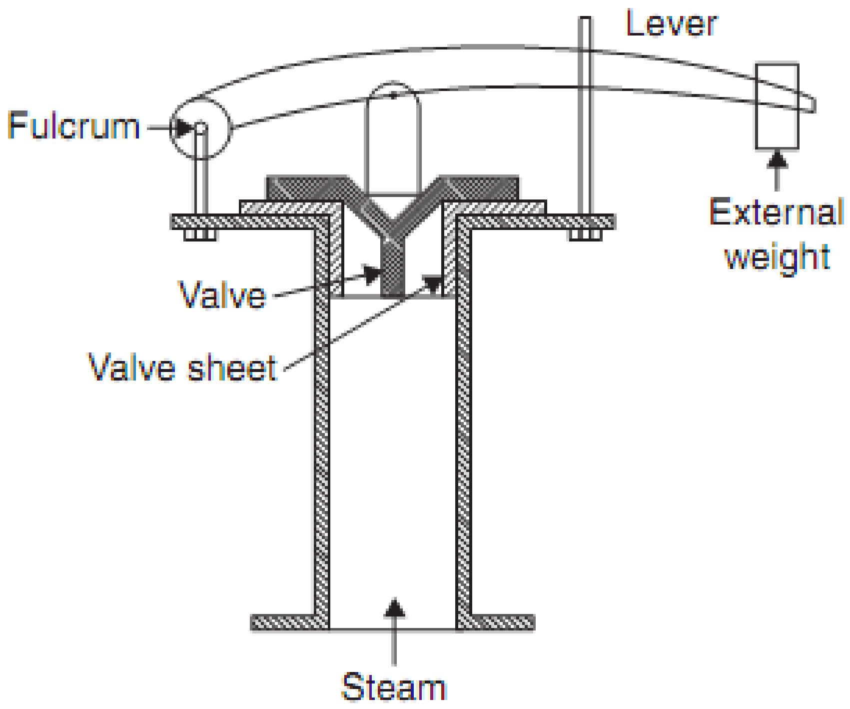


Safety Valves

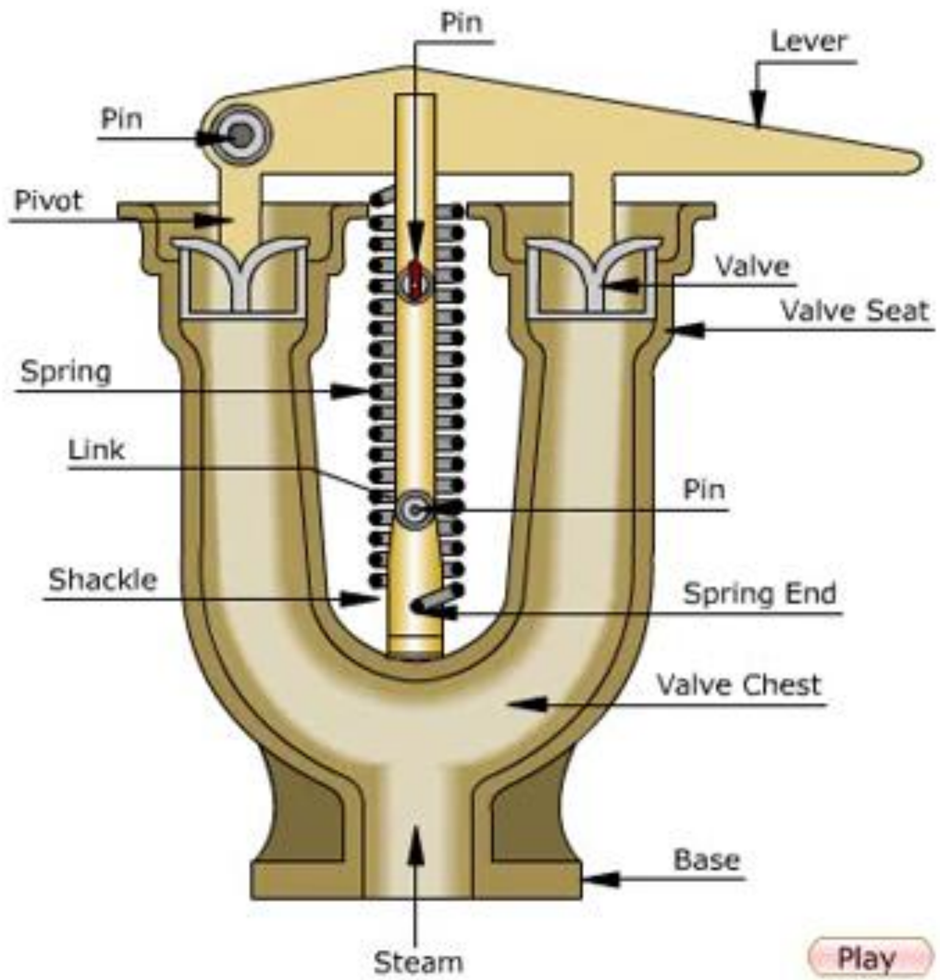


2) Sprint Loaded Safety Valve

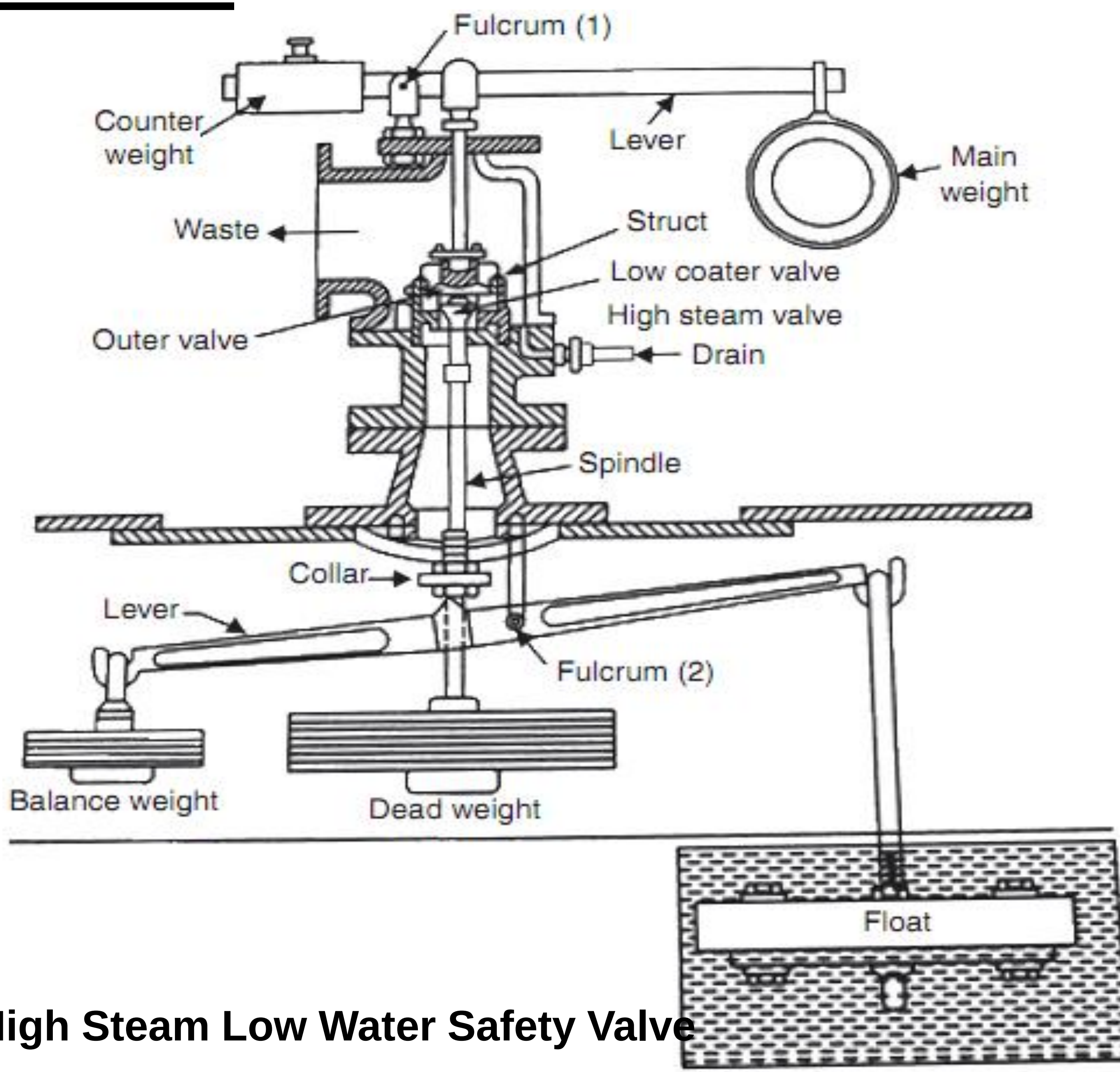


3) Lever Safety Valve

2) Sprint Loaded Safety Valve

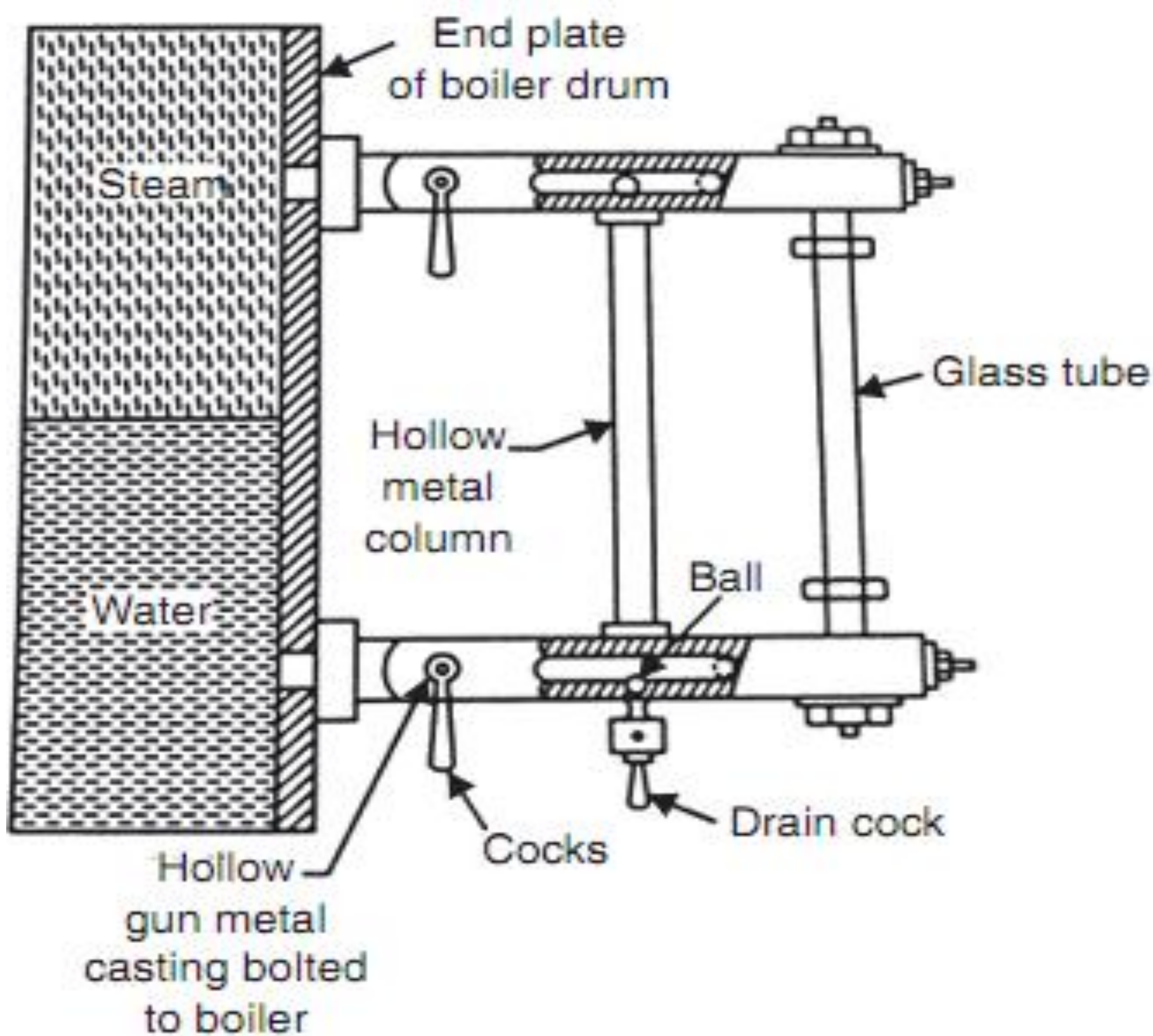


Safety Valves

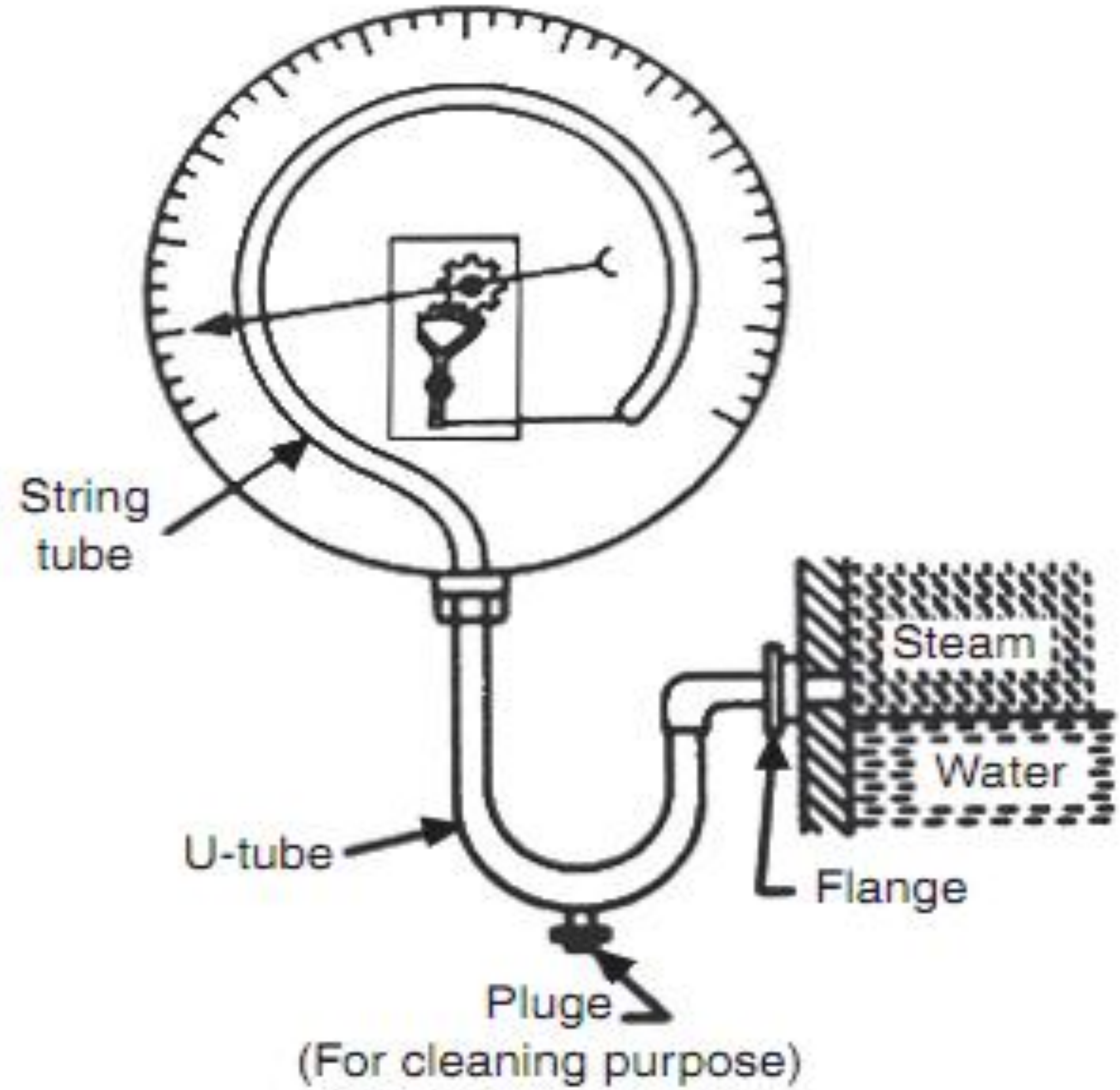


4) High Steam Low Water Safety Valve

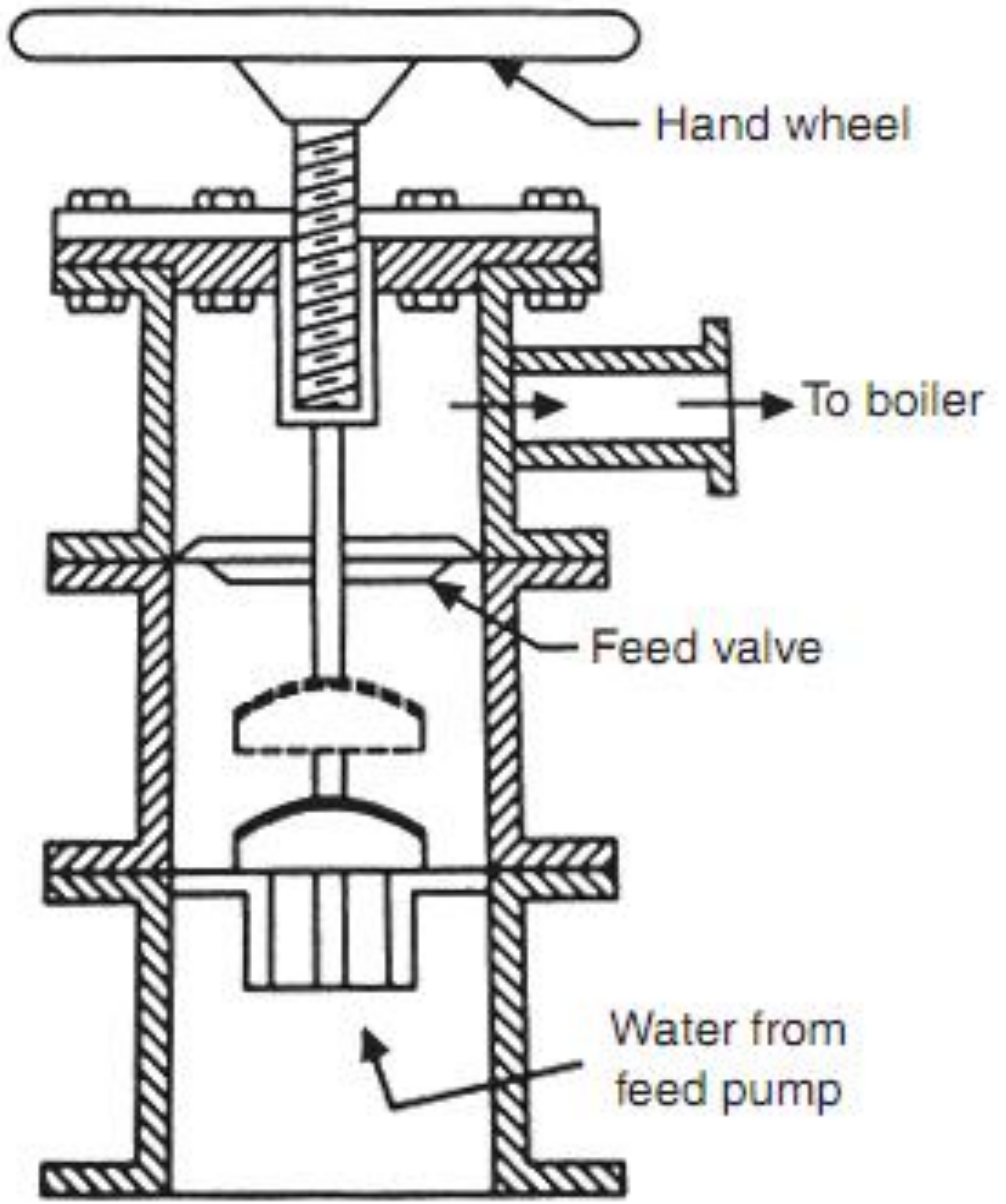
Water Level Indicator



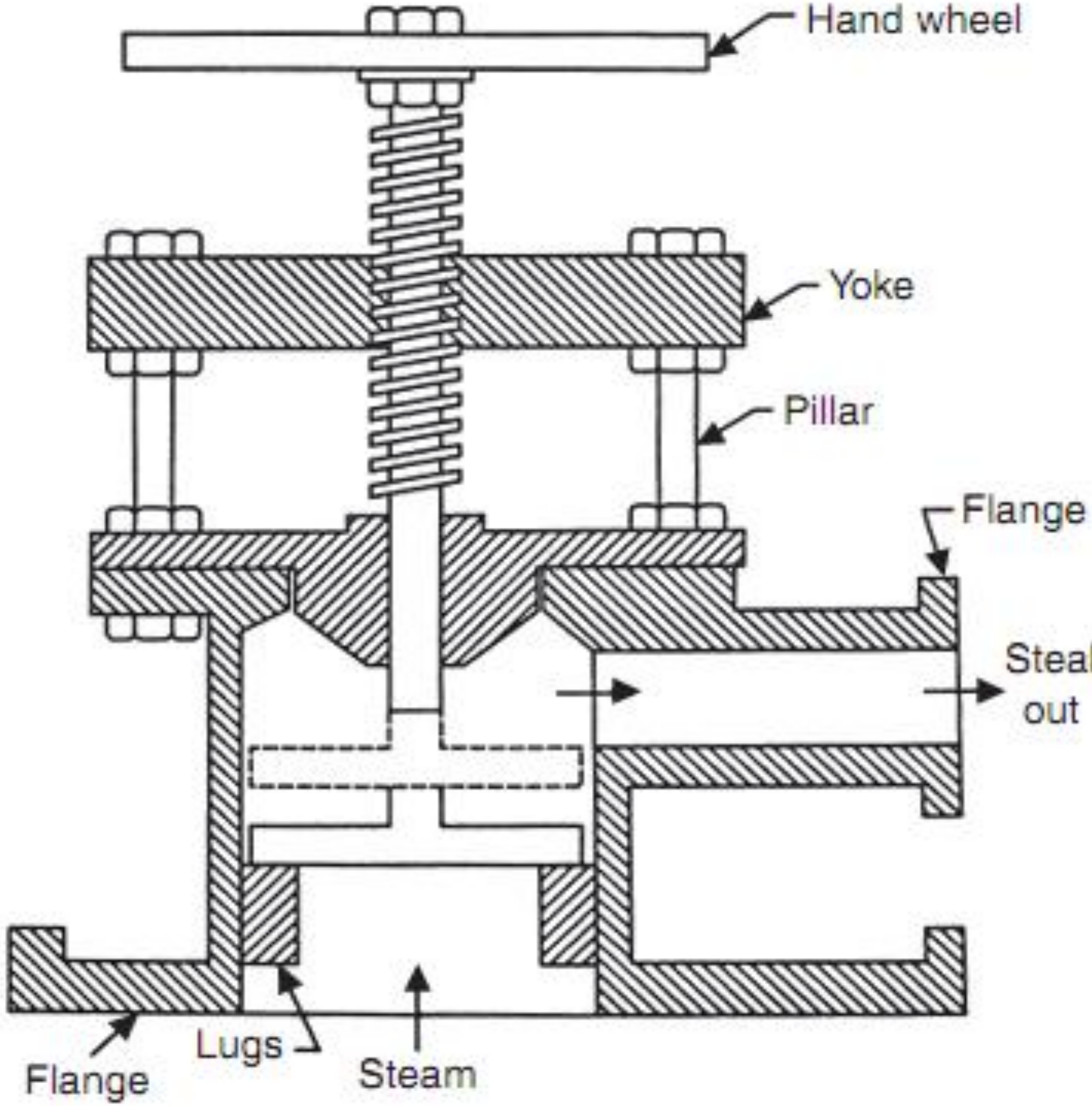
Pressure Gauge



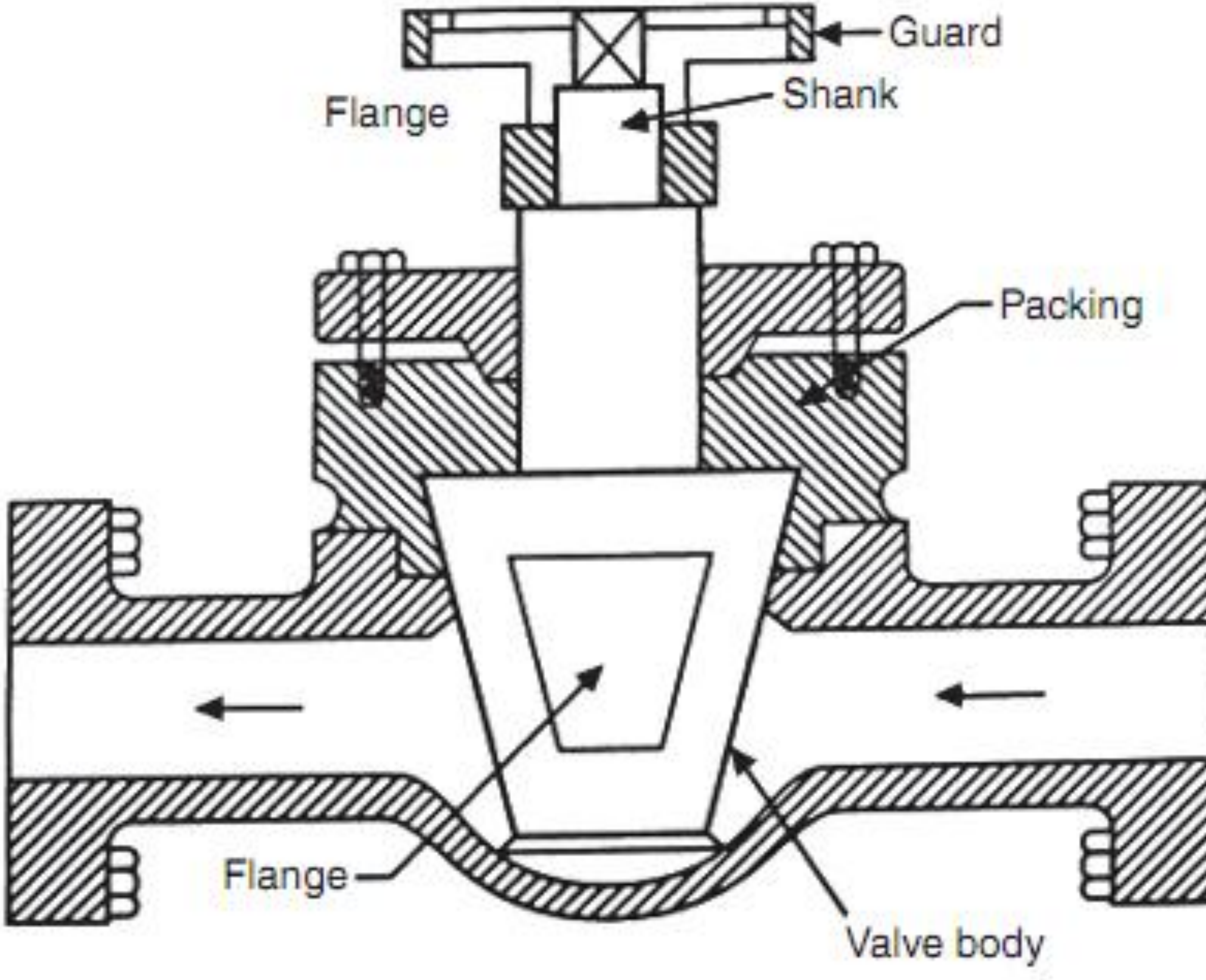
Feed Check Valve



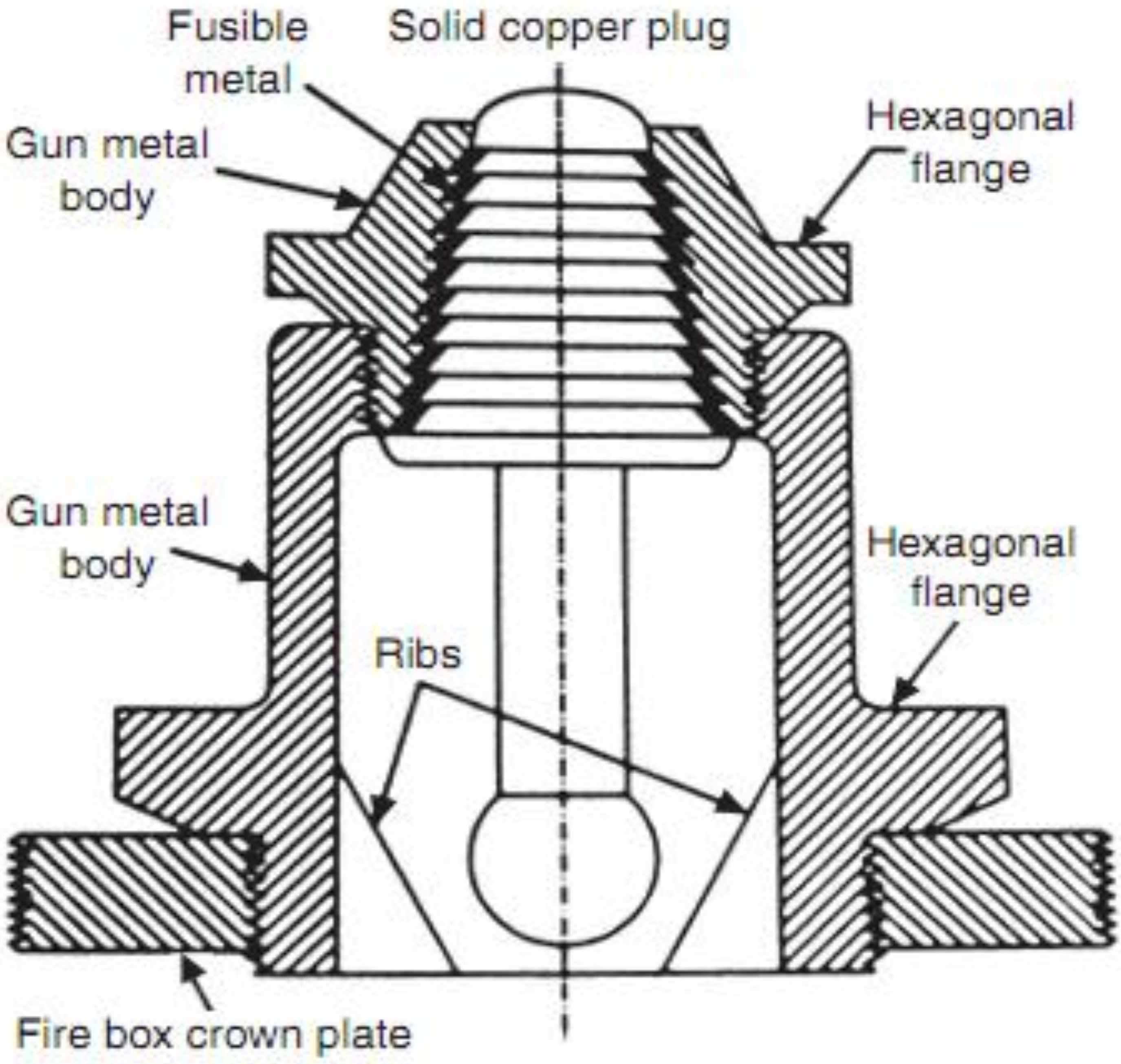
Steam Stop Valve



Blow-off Cock



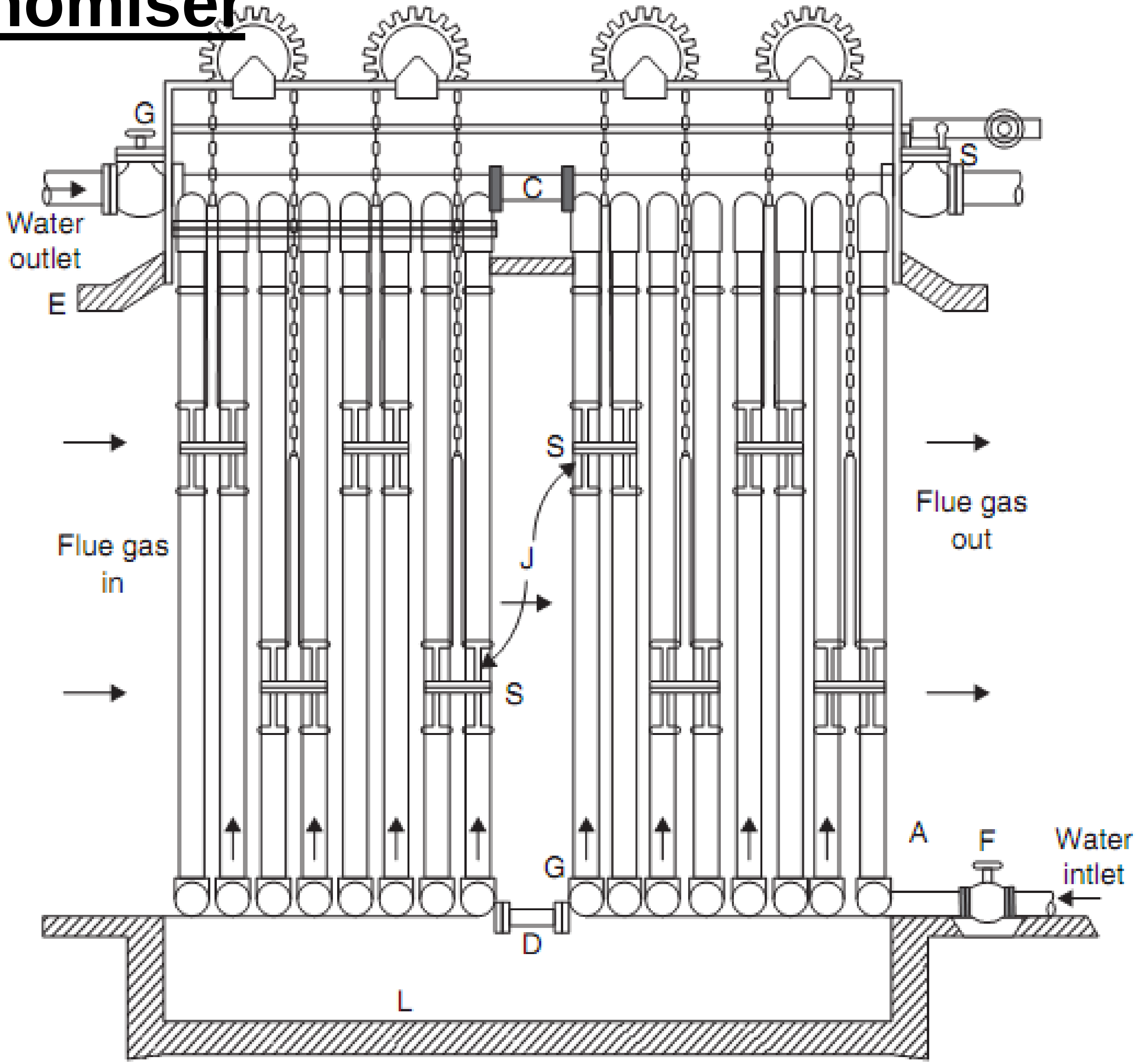
Fusible Plug



Boiler Accessories

- Economiser
- Air preheater
- Super heater
- Steam trap
- Steam separator
- Injector

Economiser


G
S
C
Water
outlet
E
S
Flue gas
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Flue gas
out
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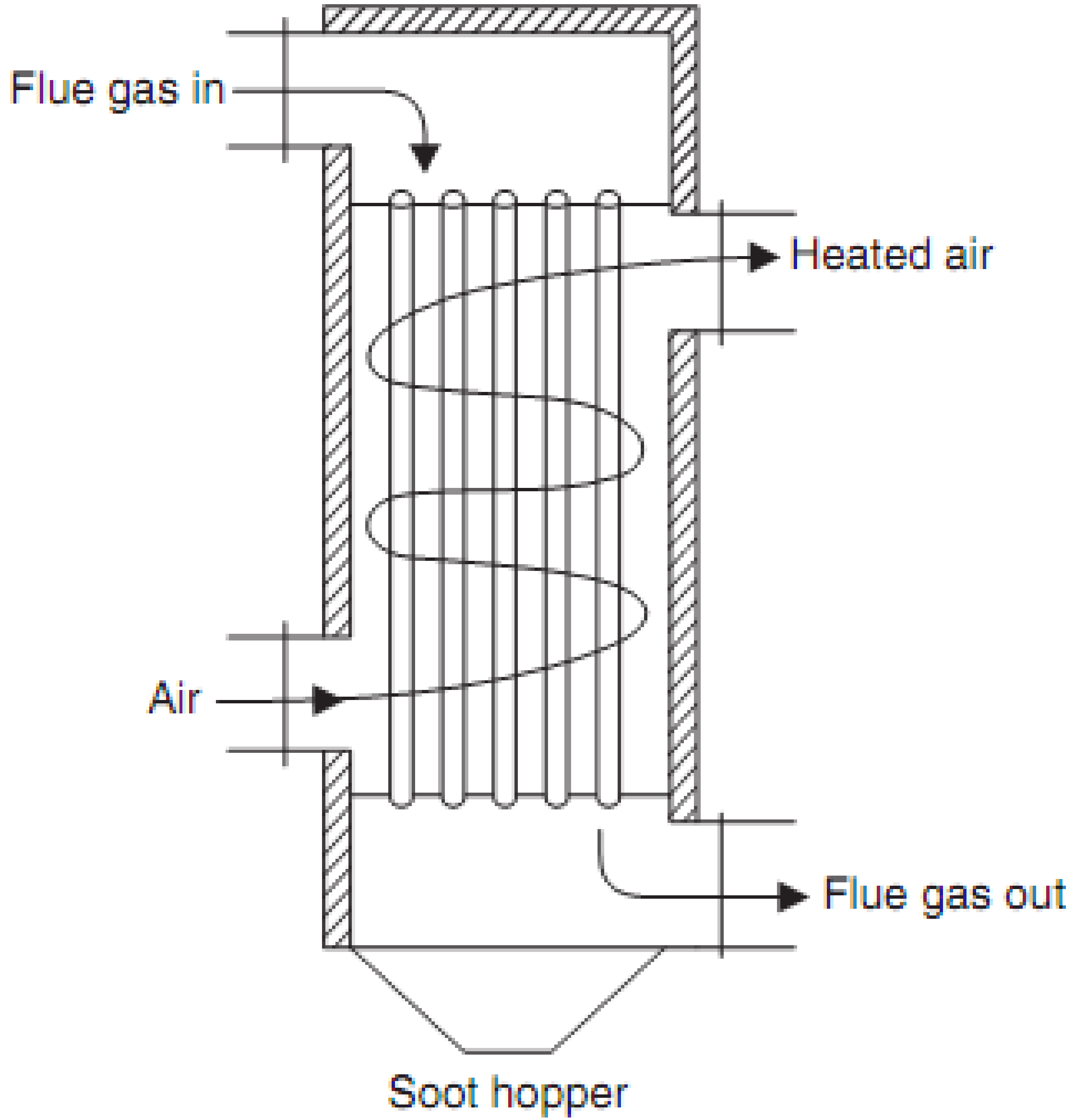
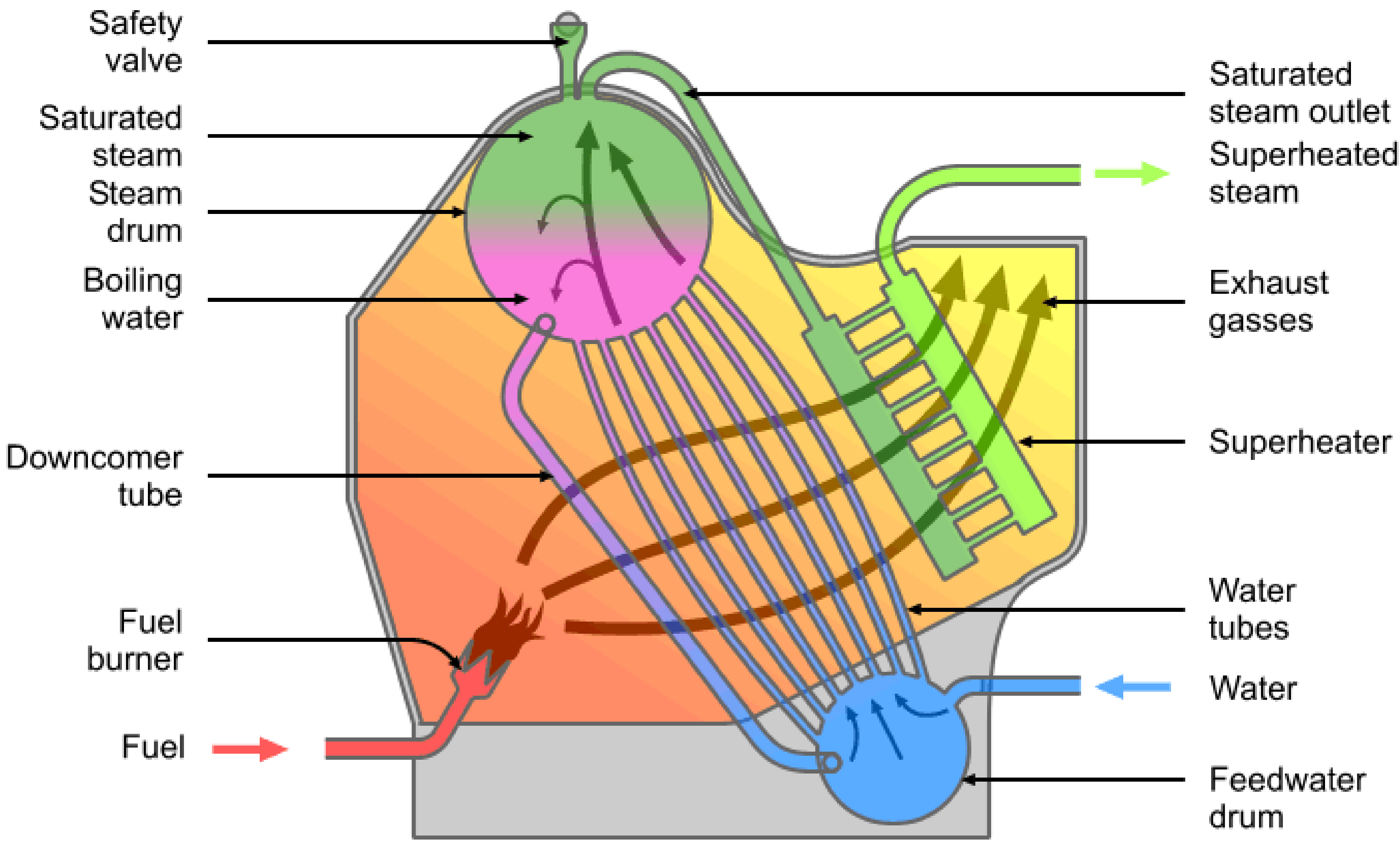
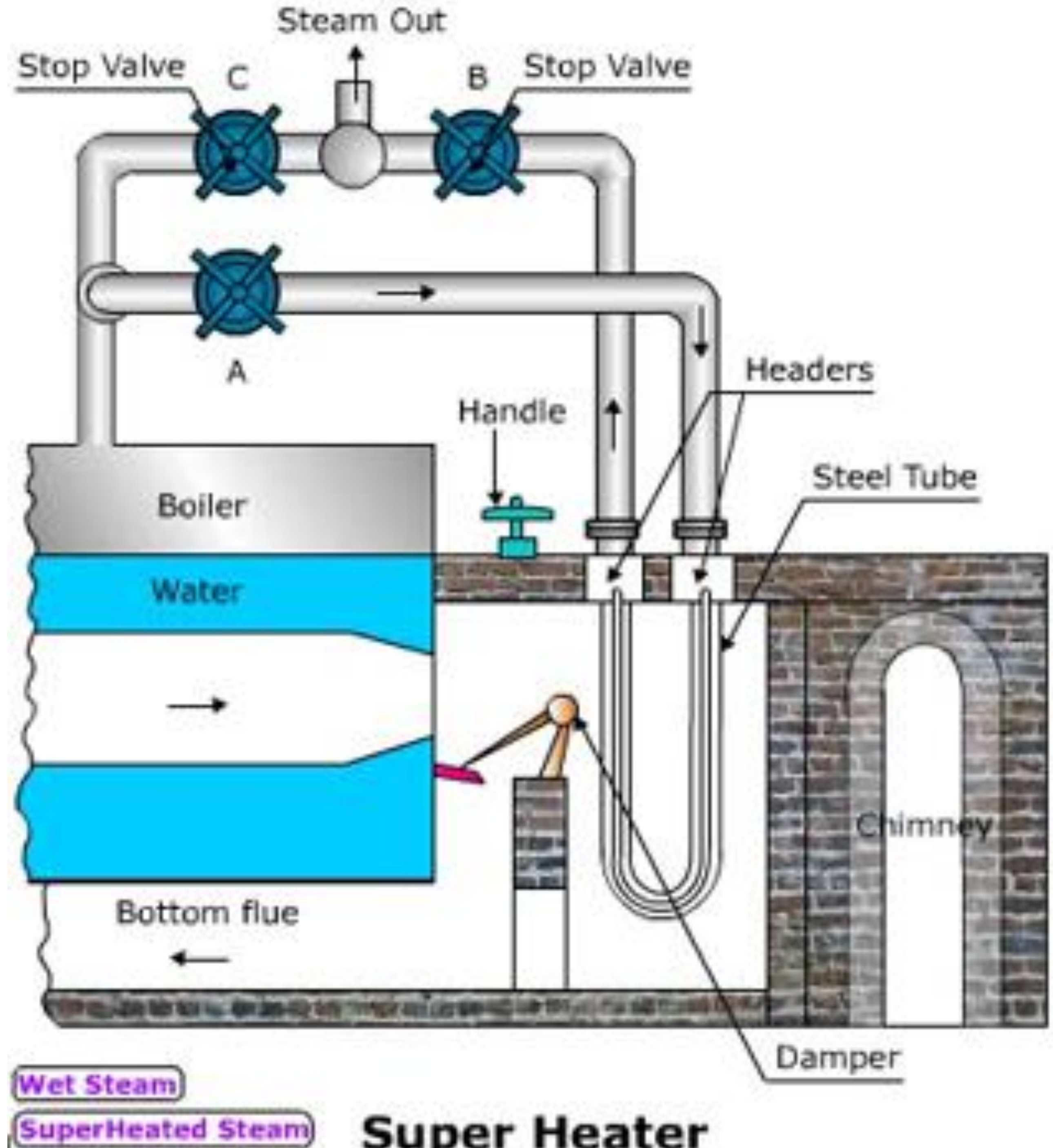
Air Preheater



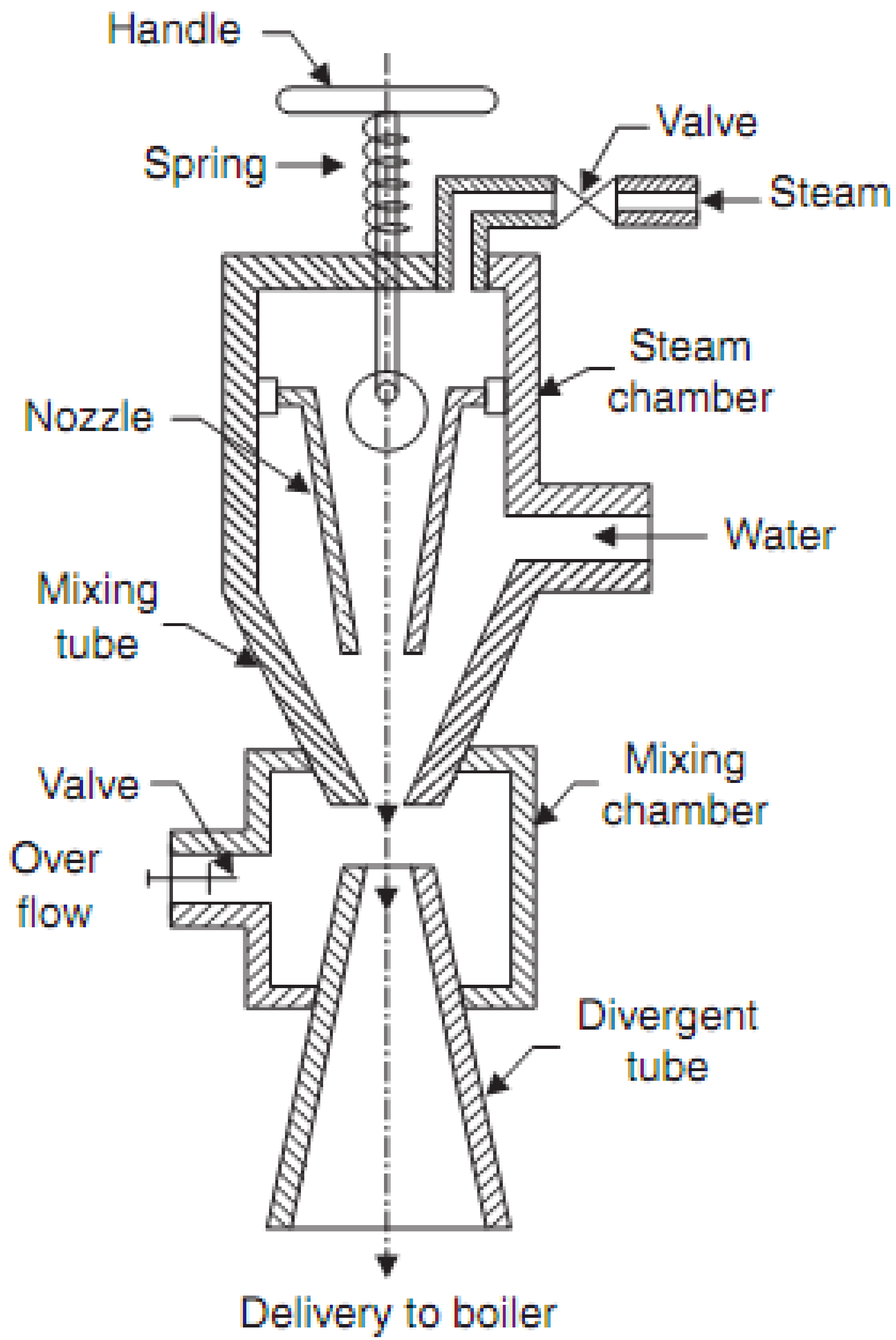
Superheater



Superheater

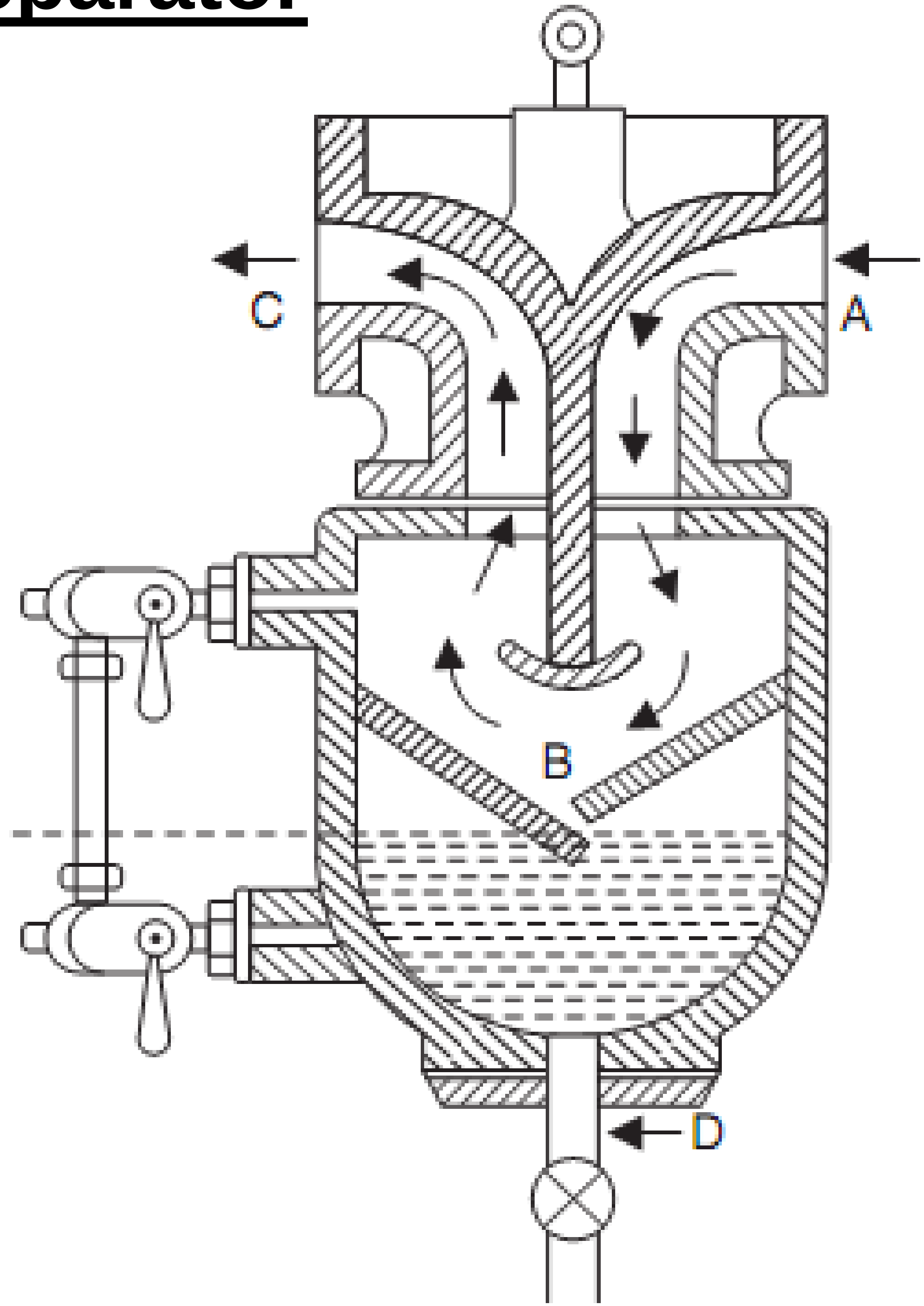


Injector

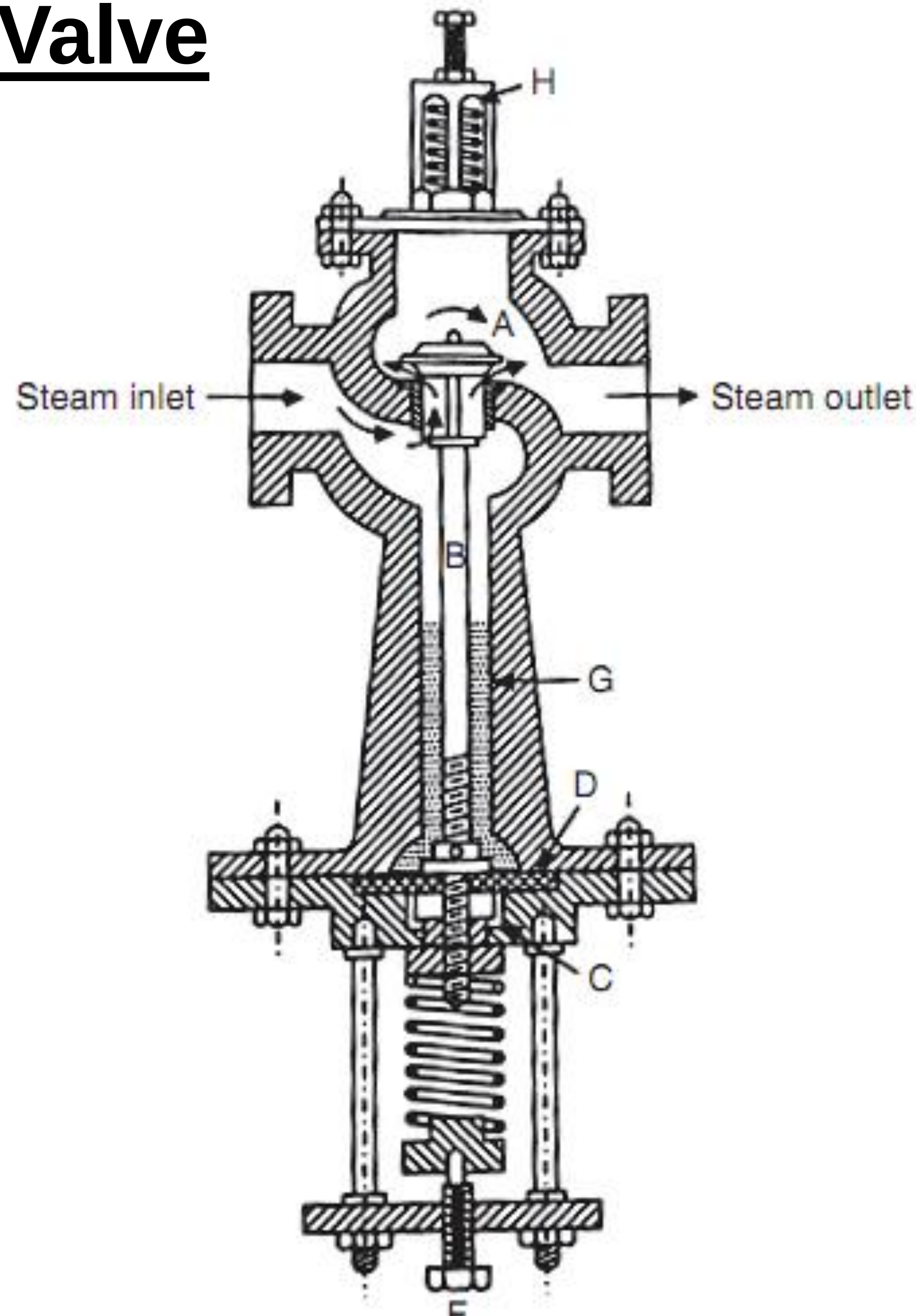


Handle
Valve
Spring
Steam
Steam chamber
Nozzle
Water
Mixing tube
Mixing chamber
Valve
Over flow
Divergent tube
Delivery to boiler

Steam Separator



Pressure Reducing Valve



Performance of Boilers

- **Evaporation Rate**: It is steam generation rate of boilers which may be expressed in terms of kg of steam per unit heating surface area or kg of steam per cubic metre of furnace volume or kg of steam per kg fuel burnt.
- **Equivalent Evaporation:** It is equivalent of evaporation of 1 kg of water at 100°C to dry and saturated steam at 100°C, standard atmospheric pressure of 1.013 bar. Hence, the equivalent evaporation of 1 kg of water at 100°C needs 2,257 kJ.
- **Factor of Evaporation**: It is ratio of heat absorbed by 1 kg of feed water under working conditions to latent heat of steam at atmospheric pressure.

$$F = \frac{h_s - h_w}{2257}, \qquad \text{where } h_s = h_f + x \cdot h_{fg}$$

- **Boiler Efficiency**: It is ratio of heat absorbed by water in boiler to heat supplied to boiler per unit time.

$$\eta_{\text{boiler}} = \frac{m_{\text{w}}\left(h_{\text{s}} - h_{\text{w}}\right)}{m_{\text{f}} \times \text{CV}}, \quad \text{where CV is calorific value of fuel}$$

Thank You…