Chapter 2
Steam Generator Design

3.1 Steam generator

It is the engineering device which generates steam at constant pressure. It is a closed vessel, generally made of steel in which vaporization of water takes place. Heat required for vaporization may be provided by the combustion of fuel in furnace, nuclear reactor, hot exhaust gases, solar radiations etc. Figure (3.1) explain the boiler diagrammatically.

3.2 Important Terms for Steam Boiler

The boiler consists from:

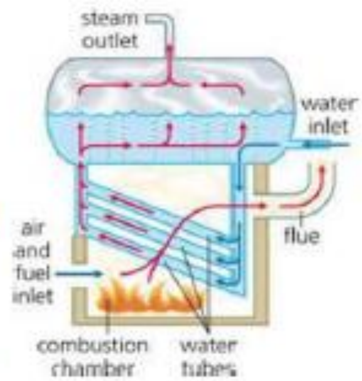

Figure (3.1) Boiler

1. **Boiler Shell**: It is cylinder made from steel plates. Its volume must be sufficient to contain water and steam.
2. **Combustion Chamber**: It's a space below the boiler shell used for fuel burning.
3. **Grate**: It is a platform in the combustion chamber, in which the fuel (coal or wood) was burning. It's made from iron bars.

4. **Furnace**: it is the space above the grate and below the boiler, in which the fuel is actually burnt. It also called **fire box**.
5. **Heating Surface**: it is the part of the boiler exposed to fire or hot gases.
6. **Mountings**: these are the fittings which are mounted on the boiler like; pressure gauge, water level indicator, safety valve …etc.
7. **Accessories**: these are the devises which form an integral part of the boiler, but not mounted on it. They are economizer, super heater, feed pump …etc.

3.3 Boiler types

If f the boilers classified according to flow of water and hot gases, there are two major types;

1. **Fire tube boiler**: the hot gases follow through the boiler pipes and water surrounds them. It's used for low and medium capacity boilers see figure (3.2).
2. **Water tube boiler**: water and its vapor follow through the boiler pipes and hot gases surround them. It's used for high capacity boilers, see figure (3.1). Table (3.1) explains the characteristics of fire tube and water tube boilers.

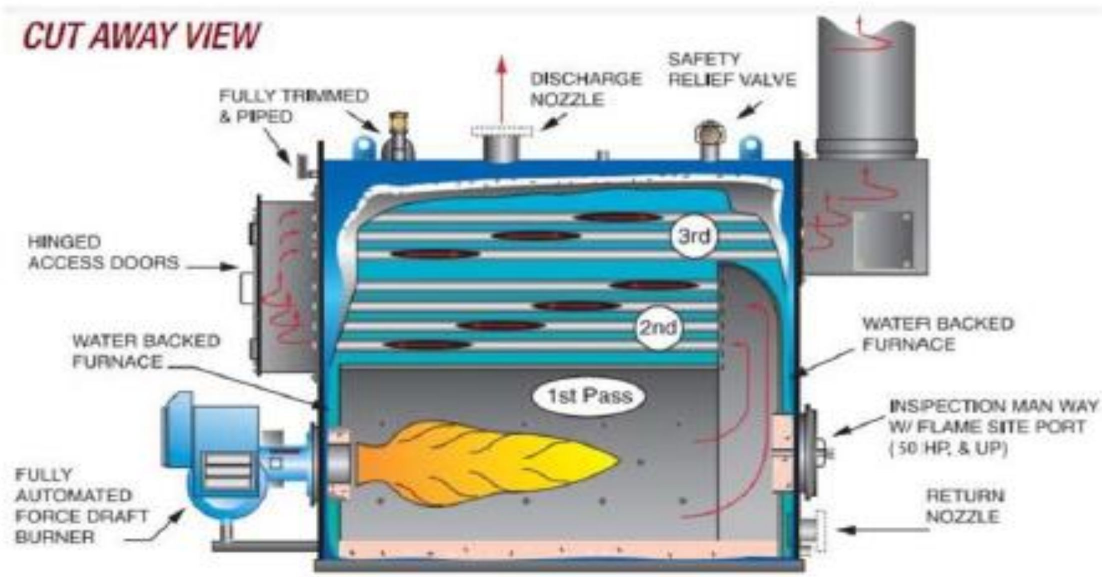

Figure (3.2) fire tube boiler.

Table (3.1) Features of fire tube and water tube boiler.

	Fire tube boiler	Water tube boiler
1	Hot gases from furnace flow through tubes which are surrounded by water.	Water circulated inside tubes which are surrounded by hot gasses.
2	Used for low and medium pressure up to 25 bar.	Used for high pressure up to 165 bar.
3	Used for low rate of steam generation up to 9 ton/hr.	Useful for high rate of steam generation 450 ton/hr.
4	The required floor area is low 5 m^2 for every 1 ton/hr.	The required floor area is high 8 m^2 for every 1 ton/hr.
5	Overall efficiency up to 75%	Overall efficiency up to 90%
6	It can be transported.	The transportation is difficult.
7	Operating coast is low.	Operating coast is high.

8	Not suitable for power plants.	Suitable for large power plants.
9	Explosion chance is low.	Explosion of the internal tubes is high.

3.4 Requirements for Good Boiler.

The good boiler must have the following features:

1. The boiler should generate steam at required pressure and quality and quantity with minimum fuel consumption. It should be economic.
2. The initial coast, installation coast, maintenance coast should be as low as possible.
3. All parts of the boiler should be easily reachable for cleaning and inspection.
4. The occupied area and weight of the boiler must be as low as possible.
5. The number of joint points in the boiler must be as low as possible to avoid leakage may occur through working.
6. The pressure drop across the boiler should be as low as possible.
7. The heat transfer rate through the boiler should be as high as possible.
8. Avoid deposition of mud and foreign materials on the inside surfaces and soot on the outer surface of the heat transferring parts.

3.5 Boiler Accessories

These are the devices which are used as integral parts of a boiler, and help in running efficiency. Though there are many types of boiler accessories, see figure (3.3), yet the following are important from the subject point of view:

1. Superheater
2. Economizer
3. Air preheater
4. Feed pump

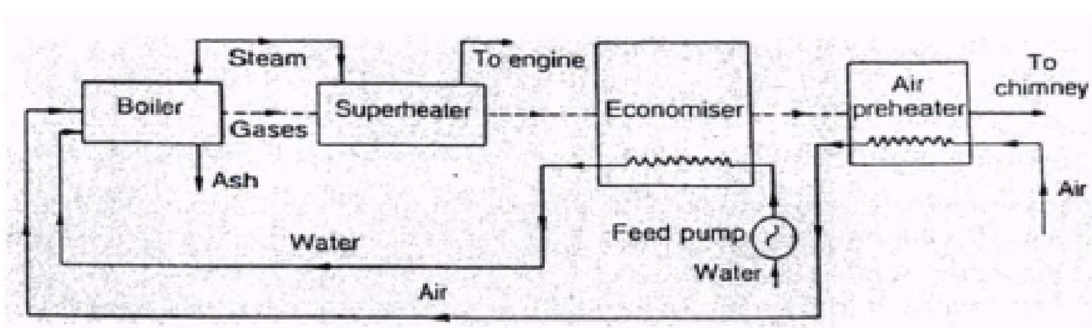

Figure (3.3) Boiler accessories.

Superheater: it is a device of steam generator unit. It is used to increase the temperature of saturated steam without raising its pressure. It is an integral part of a boiler.

Economizer: It is heat recovery device in which feed water is heated from heat available with exhaust gases. Thus hot feed water from economizer lowers the fuel requirement in combustion.

Air preheater: It is used for recovering the heat of exhaust gases by the air before being sent to furnace.

Feed pump: it is used for sending water into boiler at the pressure at which steam generation takes place. It is generally of two types: centrifugal pump and, reciprocating pump. The feed pump capacity should be greater than 15-20% of maximum continuous rating, to coverage excessive steam demand or blown out of the boiler to remove depositions and salts.

3.6. Boiler Calculations

Performance of the boiler was measured by evaporation capacity. To compare the evaporation capacity of the boilers, the inlet conditions must be identical. These conditions are: feed water temperature, working pressure, type of fuel, and the final conditions. The nominal feed water temperature is 100ºC and nominal pressure is 1.013 bar. The quantity of heat required to converting saturated liquid water at 100ºC and 1.013 bar to dry steam at the same temperature and pressure is called latent heat of evaporation.

To convert a 1 kg of distillated water at 100ºC and 1.013 bar from saturated liquid to dry vapor, the quantity of energy consumed was 2257 kj/kg. So that:

E: Equivalent evaporation

$$E = \frac{Total\ heat\ required\ to\ evaporate\ 1\ kg\ of\ feed\ water}{2257}$$

$$E = \frac{m_e(h_2 - h_1)}{2257} \qquad \text{but,} \qquad m_e = \frac{m_s}{m_f}$$

Where: E: equivalent evaporation in (kg/kg of fuel).

m_e: mass of water actually evaporated in kg/kg of fuel.

m_s: mass of water evaporated into a steam in kg.

m_f: mass of fuel in kg.

h_1: enthalpy or sensible heat of feed water entering boiler in kj/kg corresponding to T_1 °C (from steam tables).

h_2: enthalpy or total heat of steam leaving boiler in kj/kg corresponding to working pressure (from steam tables).

Note:

- if the steam leaving the boiler as wet steam $(h_2 = h_f + xh_{fg})$.
- if the steam leaving the boiler as dry steam $(h_2 = h_g)$.
- if the steam leaving the boiler as superheated steam $(h_2 = h)$ from superheated tables, or $[h_2 = h_g + C_p(T_{superheated} - T_{saturated})]$.

Where : C_p: specific heat for the superheated steam $(2.1\ kj/kg.K)$.

$T_{superheated}$: degree of superheat of the steam in (°C).

$T_{saturated}$: saturated temperature of the steam at working pressure in (°C).

F_e:Factor of Evaporation:

$$F_e = \frac{h_2 - h_1}{2257}$$

$F_e > 1$ for actual boilers.

η: Boiler Efficiency

It is defined as the ratio of the heat used in producing the staem to the heat liberated in the furnace. Sometimes is defined as the thermal efficiency of the boiler.

$$\eta = \frac{heat\ actully\ used\ in\ producing\ steam}{heat\ liberated\ in\ furnace} = \frac{m_s(h_2 - h_1)}{m_f \times C} = \frac{m_e(h_2 - h_1)}{C}$$

Where: C: calorific value of fuel in kj/kg of fuel.

Percentage of Energy Utilized through Steam Generator Part

The steam generator mainly divides into three main parts. These parts are; economizer, boiler, and super heater. Sometimes steam generator can be referred as a "Boiler". These three parts consumed the energy fuel combustion in the furnace. The percentage of energy utilized through every part of steam generator can be calculated as follows:

$$\text{percentage of energy utilized} = \frac{\text{energy utilized } through\ a\ part}{energy\ of\ combustion}$$

$$\text{percentage of energy utilized} = \frac{m_e(\Delta h)}{C} \times 100\%$$

Example (3.4): Coal fired boiler plant consumes 400 kg of coal per hour. The boiler evaporates 3200 kg of water at 44.5°C into superheated steam at a pressure of 12 bar and 274.5 °C. If the colorific value of fuel is 32760 kj/kg of coal, determine; (1) equivalent evaporation from and at 100 °C. (2) thermal efficiency of the boiler.

Solution: given

$$m_f = 400\ kg/h;\ m_s = 32300\ kg;\ T_1 = 44.5\,°C;\ p = 12\ bar;$$

$T_{super} = 275.5°C; C = 32760\ kj/kg\ of\ coal; take\ C_p = 2.12\ kj/kg.K$

(1) equivalent evaporation;

$m_e = \frac{m_s}{m_f} = \frac{3200}{400} = 8\ kg$

from saturated steam tables

$@T_1 = 44.5\,°C \qquad h_{f1} = h_f = 186.3\ kj/kg$

$@p = 12\ bar \quad T_{saturated} = 188\,°C\ \ and\ h_g = 2782.7\ kj/kg$

For the enthalpy of superheated steam leaving the boiler was;

$h_{sup} = h_g + C_p(T_{superheated} - T_{saturated}) = 2782.7 + 2.1 \times (274.5 - 188)$

$h_{sup} = 2964.4\ kj/kg = h$

Or it can be obtained with the aid of superheated steam tables.

$E = \frac{m_e(h_2 - h_1)}{2257} = \frac{8\times(2965.4 - 186.3)}{2257} = 9.85\ kg/kg\ of\ coal$

(2) thermal efficiency of the boiler.

$\eta = \frac{m_e(h_2 - h_1)}{c} = \frac{8\times(2964.4 - 186.3)}{32760} = 0.678 = 67.8\,\%$