BOILER AND STEAM SYSTEM

Boiler

The boiler is the most commonly used piece of energy conversion equipment. The boiler house or steam generation facility within any given plant is frequently referred to as the heart. A boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. In the boiler furnace, the chemical energy in the fuel is converted into heat, and it is the function of the boiler to transfer this heat to the contained water in the most efficient manner.

The boiler should also be designed to generate high quality steam for plant use. A boiler must be designed to absorb the maximum amount of heat released in the process of combustion. This heat is transferred to the boiler water through radiation, conduction and convection.

Classification of boiler

Based on construction
A) Water tube boiler: Here water circulates through the tube, which is surrounded by flame and hot gases. Generally high-pressure boilers are of water tube design.
B) Fire tube boiler: Here the hot products of combustion of fuel (flame or hot gases) pass through the tube, which are surrounded by water

Based on the application of heat
A) Direct fire boiler: e.g. Water tube boiler, Fire tube boiler
B) Indirect fire boiler: e.g. Waste heat boiler.

Based on the method of circulation of water
A) Natural circulation boiler: Boiler water circulates naturally (by density difference).
B) Assisted forced circulation boiler: Boiler water is circulated by the action of a pump.
C) Once through forced circulation boiler: Here, a pump feeds the water at one end and forces the steam through the other end of the boiler.

Based on steam generation
A) Low pressure steam boiler ( < 20 Kg )
B) Medium pressure steam boiler ( < 80 Kg )
C) High pressure boiler ( > 80 Kg )

Advantages of water tube boiler over fire tube boiler
- It can produce higher-pressure steam than that of fire tube boiler
- Steam generation is rapid than fire tube boiler
- For a given power it occupies a smaller area than a fire tube boiler
- It can be constructed to work at high pressure without excessive thickness of metal
- Heating surface area of water tube boiler is greater than that of fire tube boiler

Types of fuels
A variety of fuels are used for heating of boilers. Fuels may be classified as follows
- Solid Fuels: i.e. Wood, Coals, Bagasse, cokes, etc.
- Liquid Fuels: i.e. Alcohol, Petroleum oil, Furnace oil, Tar, etc
- Gaseous Fuels i.e. Natural gas, Coal gas, Producer gas, etc.

Steam and Steam generation (evaporation of water)
Steam is a good conveyor of heat and pressure energy. When heat energy is transferred to water, its enthalpy and physical state change (liquid to vapor). The vapor thus formed is known as steam. As heating takes place the temperature of water rises and generally its density decreases. When water is placed in a container and heated up under a constant pressure, the water temperature gradually rises. When the water temperature reaches a certain level with respect to the pressure being applied, the temperature rise stops and the water begins to boil.
(Fig: 1) This level of temperature is called a saturated temperature with respect to the pressure applied. And this is called a saturated pressure with respect to the temperature. As the pressure in the boiler rises, the boiling point of the water in the boiler also rises. For each pressure there is a corresponding boiling temperature. The required pressure at which boiler must operate is determined by the temperature required in the process work and the pressure required to transmit the steam.

Figure: 1

When 1 Kg of water is heated at atmospheric pressure from 0°C to 100°C, this temperature is reached with the addition of 100 Kcal heats. The water begins to boil and this point is known as the boiling point (at atm. pressure). With further addition of heat, there is no rise in temperature, the heat being used for evaporation of the water (change of state).

Classification of steam

Steam may be classified into two categories
- Saturated steam
- Superheated steam

Uses of steam

- Power generation
- Steam engines or Steam Turbines
- Heating
- Heat Exchangers: Heaters, Evaporators, Re-boilers etc.
- Room heater / Radiator
- Utilization in process industries such as Ammonia manufacturing, .
- Sizing and bleaching in textile industries

Enthalpy or heat content of water & steam

When a quantity of heat applied to a substance is consumed in raising the substance’s temperature, that heat is called sensible heat. When a substance is heated and its state is changed such as evaporation or melting, by the heat applied under constant temperature that heat is called latent heat.

For example, when water evaporates, the applied heat is consumed in evaporation, leaving the water temperature unchanged. In such a case, the heat is used to change only the state of water and is called latent heat or heat of vaporization. The latent heat of water is 539 kcal per kilogram of water under standard atmospheric pressure. The sum of sensible heat and latent heat is called total heat.
Enthalpy of liquid/sensible heat
The amount of heat energy in Kcal, necessary to rise 1 Kg of water from a temperature of 0°C to its temperature of boiling, at a given absolute pressure, is the enthalpy of liquid / sensible heat.

Enthalpy of evaporation / latent heat
The heat energy, in Kcal, necessary to convert 1 Kg of water into dry steam at the constant temperature and pressure, is the enthalpy of evaporation / latent heat.

Enthalpy of steam
Total enthalpy ($H_s$) of 1 Kg of dry saturated steam, reckoned above $0^\circ$C, is the sum of enthalpy of liquid ($H_l$) and the enthalpy of evaporation ($H_e$).

$$H_s = H_l + H_e$$

CONSTRUCTION SYSTEM OF NATURAL CIRCULATION TYPE BOILER

The constituents of a boiler system may be classified as follows:
- Major constructional parts
- Auxiliary equipment
- Mountings
- Instrument and control equipment

Major constructional parts of boiler
A boiler consists of the following major constructional parts:
- Boiler shell
- Furnace / Combustion chamber
- Gas burner
- Steam drum
- Water drum / mud drum
- Down comer
- Riser

Boiler shell
It is made up of steel plates bent into cylindrical form and welded together. The ends of the shell are closed by means of end plates. A boiler shell should have sufficient capacity to contain water and steam.

Furnace / Combustion chamber
It is the space generally below the boiler shell. It is a close chamber where the fuel is burned to produce heat. Generally the wall of furnace is insulated to reduce the radiant heat loss.

Gas burner
The burner is a device to get the fuel into the suitable form for combustion, to mix it with the air and to maintain combustion.

Steam drum
A drum in which entrained water is effectively separated from saturated steam

Water drum / mud drum
A drum, which contains water and is located at the lowest portion of the boiler

Down comer
A tube / bundle of tubes, connected between steam drum and water drum, to feed water to water drum, which is situated at opposite of the hot part of the boiler
Riser
A tube / bundle of tubes, connected with steam drum and water drum, which is situated at the hot part of the boiler. Here water is converted to steam.

Auxiliary equipment
These are the devices which form an integral part of a boiler but are not mounted on it. Boilers need accessories & auxiliaries to operate the boiler efficiently and safely. This includes
  - Feed water pump
  - Deaerator
  - Feed water heater / economizer
  - Feed water filters
  - Air heaters
  - Superheaters
  - Desuperheaters
  - Stack
  - IDF (Induced draft fan)
  - FDF (forced draft fan)

Feed water pump
It is used to supply water to boiler. It may be reciprocating or centrifugal pump.

Deaerator
It is a device to remove dissolved oxygen from the boiler feed water.

Feed water heater / Economizer
It is used to heat the feed water by utilizing waste heat of the flue gas. It decreases the cost of steam production for about 15~20 % and increases the efficiency of the boiler.

Feed water filters
The condensate from condensing equipment bears a considerable quantity of impurities. It is advisable to filter this condensed steam before delivering to boiler, which is done in feed water filter.

Air heater
It is a heat exchanger which is used to heat combustion air before entering the furnace. The hotter air supply increases the furnace temperature and hence increases transmission of radiant heat to the boiler.

Superheater
It is a simple heat exchanger for imparting additional energy to steam above that contained in the saturated state for a given pressure.

Desuperheater
It is a control device, which controls the temperature of superheated steam by spraying feed water.

Stack
It is a chimney, through which flue gases of the boiler are discharged.

IDF (Induced draft fan)
A fan, which draws the air/flue gas from the furnace. It is placed near the base of the chimney.

FDF (force draft fan)
A fan, which is used to supply air into the furnace to get complete combustion.
Mountings
These are fittings which are mounted on the boiler for its proper functioning. To operate a boiler smoothly and safely, some mountings are required which are as follows
- Water level indicator
- Pressure gages
- Safety valves
- Steam supply valve
- Blow-down valve
- Feed water check valve

**Water level indicator**
It is used to show the level of water in the drum or shell of the boiler

**Pressure gages**
It is used to measure the steam pressure in the boiler

**Safety valves**
It is a mechanical pressure control device, which acts at the time when the steam pressure exceed the working pressure and thus it saves the boiler.

**Steam supply valve**
It controls the flow of steam from boiler to main steam pipe line. It can cut the total steam flow in need. It is the biggest valve of a boiler.

**Blow-down valve**
A valve, located at the lowest point in the boiler, allowing water and suspended solids to escape.

**Feed water check valve**
It is a non-return valve, which checks back flow of feed water from the steam drum.

**Instrument and control equipment**
These items attached to a boiler give an indication to the operator of the conditions that exist within the boiler and thus enable him to ensure that these are within the safety limits and operational parameters for which the boiler was designed. Examples of indicated quantities are operating pressures, temperatures, flows and water levels.

**Controls** items carry out the function of regulating the various quantities indicated by the instruments and which can be arranged, with interlocks, to shut the plant down if any values pass outside the allowable operating range. Boiler control systems can Manual as well as Automatic.