CHAPTER TWO: Boiler Operation Maintenance & Safety Study Guide

2.1 Boiler Design and Construction

<u>Boiler</u>: **A boiler is a closed vessel in which water is heated, steam is generated, superheated or any combination thereof under pressure or vacuum by the direct application of heat from combustible fuels or electricity**. The steam produced is used for:

(*i*) Producing mechanical work by expanding it in steam engine or steam turbine.
(*ii*) Heating the residential and industrial buildings
(*iii*) Performing certain processes in the sugar mills, chemical and textile industries.

Usually boilers are coal or oil fired. A boiler should fulfill the following requirements:

(*i*) Safety. The boiler should be safe under operating conditions.
(*ii*) Accessibility. The various parts of the boiler should be accessible for repair and maintenance.
(*iii*) Capacity. The boiler should be capable of supplying steam according to the requirements.
(*iv*) Efficiency. To permit efficient operation, the boiler should be able to absorb a maximum amount of heat produced due to burning of fuel in the furnace.
(*v*) It should be simple in construction and its maintenance cost should be low.
(*vi*) Its initial cost should be low.
(*vii*) The boiler should have no joints exposed to flames.
(*viii*) The boiler should be capable of quick starting and loading.

The performance of a boiler may be measured in terms of its evaporative capacity also called power of a boiler. It is defined as the amount of water evaporated or steam produced in kg per hour. It may also be expressed in kg per kg of fuel burnt or kg/hr/m2 of heating surface.

2.1.1 Boiler Classifications

Boilers are classified by their pressure capacity, their design type and by their use.
High & Low Pressure Boilers –

The **M.A.W.P** or Maximum Allowable Working Pressure is the highest amount of pressure that the vessel is designed to withstand. Pressure is measured in terms of pounds per square inch or **psi**. **Psig** (gauge) indicates gauge pressure, which ignores the atmospheric pressure. **Psia** (absolute) is the sum of gauge pressure plus the atmospheric pressure at that location, which varies based on altitude. A **compound gauge** measures indicates pressure and vacuum.

• **Low-pressure boilers** are designed to withstand a maximum of 15 psig steam or a M.A.W.P. 160 psig water.

The boilers can be classified according to the following criteria.

<u>According to flow of water and hot gases:</u>

1. Water tube.
2. Fire tube.

In water tube boilers, water circulates through the tubes and hot products of combustion flow over these tubes. In fire tube boiler the hot products of combustion pass through the tubes, which are surrounded, by water. Fire tube boilers have low initial cost, and are more compacts. But they are more likely to explosion, water volume is large and due to poor circulation they cannot meet quickly the change in steam demand. For the same output the outer shell of fire tube boilers is much larger than the shell of water-tube boiler. Water tube boilers require less weight of metal for a given size, are less liable to explosion, produce higher pressure, are accessible and can response quickly to change in steam demand. Tubes and drums of water-tube boilers are smaller than that of fire-tube boilers and due to smaller size of drum higher pressure can be used easily. Water-tube boilers require lesser floor space. The efficiency of water-tube boilers is more.

<u>According to position of furnace.</u>

(*i*) Internally fired (*ii*) Externally fired

In internally fired boilers the grate combustion chamber are enclosed within the boiler shell. Whereas in case of extremely fired boilers and furnace and grate are separated from the boiler shell.

<u>According to the position of principle axis.</u>

(*i*) Vertical (*ii*) Horizontal (*iii*) Inclined.

According to application.

(*i*) Stationary, (*ii*) Mobile, (Marine, Locomotive).

According to the circulating water.

(*i*) Natural circulation (*ii*) Forced circulation.

According to steam pressure:

(*i*) Low pressure (*ii*) Medium pressure (*iii*) Higher pressure

Water tube boilers are classified as follows:

1. Horizontal straight tube boilers

(*a*) Longitudinal drum (*b*) Cross-drum.

2. Bent tube boilers

(*a*) Two drum (*b*) Three drum

(*c*) Low head three drum (*d*) four drum.

3. Cyclone fired boilers

Various advantages of water tube boilers are as follows:

(*i*) High pressure of the order of 140 kg/cm2 can be obtained.

(*ii*) Heating surface is large. Therefore steam can be generated easily.

(*iii*) Large heating surface can be obtained by use of large number of tubes.

(*iv*)Because of high movement of water in the tubes the rate of heat transfer becomes large resulting into a greater efficiency.

Fire tube boilers are classified as follows:

l. External furnace:

(*i*) Horizontal return tubular

(*ii*) Short fire box

(*iii*) Compact.

2. Internal furnace:

(*i*) Horizontal tubular

(*a*) Short fire box (*b*) Locomotive (*c*) Compact (*d*) Scotch.

(*ii*) Vertical tubular.

(*a*) Straight vertical shell, vertical tube

(*b*) Cochran (vertical shell) horizontal tube.

Various advantages of fire tube boilers are as follows.

(*i*) Low cost

(*ii*) Fluctuations of steam demand can be met easily

(*iii*) It is compact in size.

2.1.2 Fire-Tube Boiler

This boiler consists of a cylindrical shell with its crown having a spherical shape. The furnace is also hemispherical in shape. The grate is also placed at the bottom of the furnace and the ash-pit is located below the grate. The coal is fed into the grate through the fire door and ash formed is collected in the ash-pit located just below the grate and it is removed manually. The furnace and the combustion chamber are connected through a pipe. The back of the combustion chamber is lined with firebricks. The hot gases from the combustion chamber flow through

the nest of horizontal fire tubes (generally 6.25 cm in external diameter and 165 to 170 in number). The passing through the fire tubes transfers a large portion of the heat to the water by convection. The flue gases coming out of fire tubes are finally discharged to the atmosphere through chimney (Fig.1&2). The spherical top and spherical shape of firebox are the special features of this boiler. These shapes require least material for the volume. The hemi spherical crown of the boiler shell gives maximum strength to withstand the pressure of the steam inside the boiler. The hemi-spherical crown of the fire box is advantageous for resisting intense heat. This shape is also advantageous for the absorption of the radiant heat from the furnace.
Coal or oil can be used as fuel in this boiler. If oil is used as fuel, no grate is provided but the bottom of the furnace is lined with firebricks. Oil burners are fitted at a suitable location below the fire door. A manhole near the top of the crown of shell is provided for cleaning. In addition to this, a number of hand-holes are provided around the outer shell for cleaning purposes. The smoke box is provided with doors for cleaning of the interior of the fire tubes.
The airflow through the grate is caused by means of the draught produced by the chimney. A damper is placed inside the chimney (not shown) to control the discharge of hot gases from the chimney and thereby the supply of air to the grate is controlled. The chimney may also be provided with a steam nozzle (not shown; to discharge the flue gases faster through the chimney. The steam to the nozzle is supplied from the boiler. The outstanding features of this boiler are listed below:
1. It is very compact and requires minimum floor area.
2. Any type of fuel can be used with this boiler.
3. It is well suited for small capacity requirements.
4. It gives about 70% thermal efficiency with coal firing and about 75% with oil firing.
5. The ratio of grate area to the heating surface area varies from 10: 1 to 25: 1.

It is provided with all required mountings. The function of each is briefly described below:

1. Pressure Gauge:
This indicates the pressure of the steam in the boiler.

2. Water Level Indicator:
This indicates the water level in the boiler, the water level in the boiler should not fall below a particular level otherwise the boiler will be overheated and the tubes may burn out.

3. Safety Valve:

The function of the safety valve is to prevent the increase of steam pressure in the holler above its design pressure. When the pressure increases above design pressure, the valve opens and discharges the steam to the atmosphere. When this pressure falls just below design pressure, the valve closes automatically. Usually the valve is spring controlled.

4. Fusible Plug:

If the water level in the boiler falls below a predetermined level, the boiler shell and tubes will be overheated. And if it is continued, the tubes may burn, as the water cover will be removed. It can he prevented by stopping the burning of fuel on the grate. When the temperature of the shell increases above a particular level, the fusible plug, which is mounted over the grate as shown in the Fig. 1, melts and forms an opening. The high-pressure steam pushes the remaining water through this hole on the grate and the fire is *extinguished.*

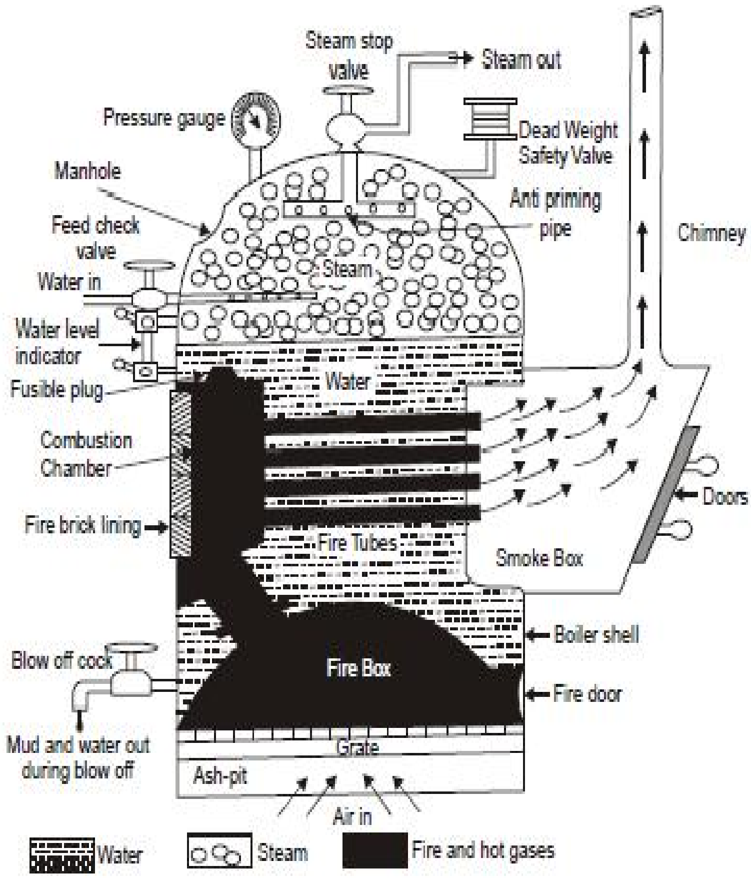

Fig. (1) Fire-tube boiler with accessories

5. Blow-off Cock:

The water supplied to the boiler always contains impurities like mud, sand and, salt Due to heating, these are deposited at the bottom of the boiler, and if they are not removed, they are accumulated at the bottom of the boiler and reduce its capacity and heat transfer rates. Also the salt content will goes on increasing due to evaporation of water. These deposited salts are removed with the help of blow off cock. The blow-off cock is located at the bottom of the boiler as shown in the figure and is operated only when the boiler is running. When the blow-off cock is opened during the running of the boiler, the high-pressure steam pushes the water and the collected material at the bottom is blown out. Blowing some water out also reduces the concentration of the salt. The blow-off cock is operated after every 5 to 6 hours of working for few minutes. This keeps the boiler clean.

6. Steam Stop Valve:

It regulates the flow of steam supply outside. The steam from the boiler first enters into an ant-priming pipe where most of the water particles associated with steam is removed.

7. Feed Check Valve:

The high pressure feed water is supplied to the boiler through this valve.
This valve opens towards the boiler only and feeds the water to the boiler. If the feed water pressure is less than the boiler steam pressure then this valve remains closed and prevents the back flow of steam through the valve.

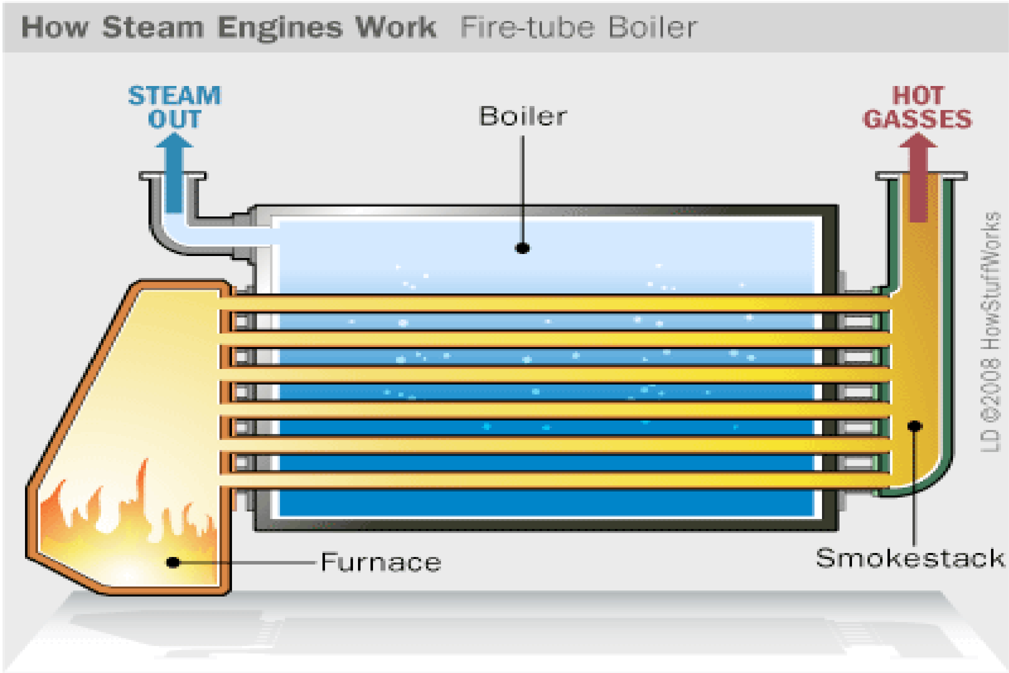

Fig. (2) Shape of fire-tube

2.1.3 Water-tube boilers:

• **Water-tube boilers** have water running through the tubes and fire or gases of combustion surrounding the tubes. The water tubes are connected into a steam drum at the top and a mud drum at the bottom. The fire is in the **Combustion chamber**. The boiler design can also be identified by the shape of the tube configuration, with the common types being called A, O, and D style boilers. The **cast iron sectional boiler** is neither fire tube nor water tube though it has some operating characteristics of a water tube boiler. The water is inside the sections and the fire is outside the sections. Cast iron sectionals used for steam heating may have distinct operating problems that are not typically found in other boiler types, such as the intolerance for poor water chemistry.

• A boiler may be classified as either a **steam boiler** or **hot water boiler**. The vessels are the same and the **boiler trim** (controls & piping) determine the use of the vessel. A steam boiler must maintain a water level covering the top of the heating (tube) surfaces while leaving room for steam production. A hot water boiler is completely full of water over the top of the boiler into the expansion tank.

INDUSTRIAL Water Tube BOILERS:

The boilers are generally required in power station, chemical industries, paper industries, pharmaceutical industries and many others. Efficiency, reliability and cost are major factors in the design of industrial boilers similar to central stations. Boiler's capacity varies from 100 to 400 tons of steam per hour. Industrial companies in foreign countries with large steam demands have considerable interest in cogeneration, the simultaneous production of steam and electricity because of federal legislation. High temperature and high pressure boilers 550°C and up to critical pressure) are now-a-days used even though high pressure and temperature are rarely, needed to. Process requirement but they are used to generate electricity to surging prices of the oil, most of the industrial boilers are designed to use wood, municipal - pulverized coal, industrial solid waste and refinery gas few industrial boilers which are in common use are discussed below.

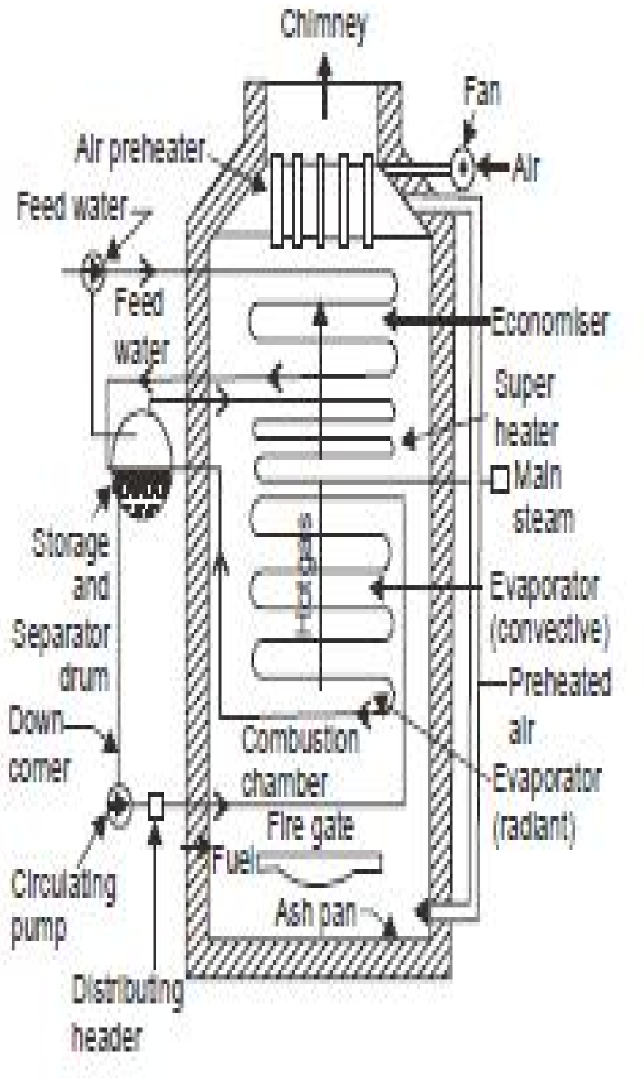

Fig.3 simple water-tube boiler layout

MERITS AND DEMERITS OF WATER TUBE BOILERS OVER FIRE TUBE BOILERS MERITS

1. Generation of steam is much quicker due to small ratio of water content to steam content. This also helps in reaching the steaming temperature in short time.
2. Its evaporative capacity is considerably larger and the steam pressure range is also high-200 bar.
3. Heating surfaces are more effective as the hot gases travel at right angles to the direction of water flow.
4. The combustion efficiency is higher because complete combustion of fuel is possible as the combustion space is much larger.
5. The thermal stresses in the boiler parts are less as different parts of the boiler remain at uniform temperature due to quick circulation of water.
6. The boiler can be easily transported and erected as its different parts can be separated.
7. Damage due to the bursting of water tube is less serious. Therefore, water tube boilers are sometimes called safety boilers.
8. All parts of the water tube boilers are easily accessible for cleaning, inspecting and repairing.
9. The water tube boiler's furnace area can be easily altered to meet the fuel requirements

Demerits:

1. It is less suitable for impure and sedimentary water, as a small deposit of scale may cause the overheating and bursting of tube. Therefore, use of pure feed water is essential.
2. They require careful attention. The maintenance costs are higher.
3. Failure in feed water supply even for short period is liable to make the boiler over-heated.

Boiler Lay-up:

Any extended period of time (summer) during which a boiler(s) is idle and is not expected to operate. Lockout/Tag out boiler(s) and shut-off gas supply.

A non-operational steam boiler should be filled to the top with chemically treated feed water or condensate to minimize corrosion during lay-up. Inactive heating systems, along with boilers, in vacated buildings, should be drained due to danger of freezing.

Boiler Pass:

The path of travel of the combustion gases through the full length of boiler including the initial pass in the primary combustion zone. A boiler may have as many as four passes.

Boiler Programmer:

A boiler programmer is the mastermind that controls the firing cycle of a boiler. It performs two functions. (1) Senses the presence of a flame during pilot and main flame and (2) programs the operation of a burner system so that motors, blowers, ignition and fuel valves are energized only when they are needed, and then in proper sequence. **Note:** Not all boilers have programmers.

Boiler System:

A system comprised of the boiler(s), its controls, safety devices, interconnecting piping, vessels, valves, fittings and pumps.

Breeching:

A duct for the transport of the products of combustion between the boilers and the stack.

Forced-Draft Fan:

A fan, in boilers with power burners that supplies air for combustion of fuel as well as draft.

Furnace:

An enclosed space provided for the combustion of fuel.

Gage Glass:

The transparent part of a water gage assembly connected directly or through a water column to the boiler, below and above the waterline, to indicate the water level in a steam boiler.

Induced-Draft Fan:

fan, generally mounted on horizontal breeching, which pulls the flue gases out of some boilers, with atmospheric burners, into the stack.

Limit Control:

A device, with a manual reset, which shuts down the burner when operating limits are surpassed.

Low Water Fuel Cut-Off. (LWC):

A device, most often float-operated, which shuts down the fuel burner when the water level in the boiler drops below its operating level. Two low water fuel cutoffs are required on steam boilers. The primary LWC has a combination condensate feed pump control and an auxiliary control that automatically cuts off the fuel supply if the proper water level is not being maintained. The secondary LWC is set one inch lower than the primary and it causes a safety shutdown, requiring manual reset. **Note:** Even though most hot water heating boilers have a LWC, by code one is required only on boilers with capacities of 400,000 Btu/hr or greater.

Makeup Water:

Water introduced into the boiler, from outside the boiler system, to replace that lost (leaks) or removed from the system.

Manhole:

The opening in a pressure vessel of sufficient size to permit a man to enter.

Operating Control:

A device which automatically controls the operation of a fuel burner to maintain the desired temperature or pressure.

PH:

A logarithmic scale used to measure the degree of acidity or alkalinity of a solution. The scale runs from 1 (strong acid) to 14 (strong alkali) with 7 (distilled water) as the neutral point.

Power Burners:

Power burners are designated to operate with a furnace pressure higher than atmospheric and are equipped with sufficient blower capacity to force products of combustion through the boiler without the help of natural or induced draft.

Pigtail Loop:

Each pressure control device on steam boilers should have a pigtail loop, which acts as a steam trap, installed between the controller, and the boiler. This prevents the controller's diaphragm or bellows from seeing any steam, thus preventing damage to it.

Safety Relief Valve:

An automatic pressure-relieving device required by code to be used on hot water heating boilers that is actuated by the pressure generated within the boiler. Valves of this type are spring loaded without full-opening action and have a factory set nonadjustable pressure setting. A safety relief valve set pressure must be equal to or less than boiler Maximum Allowable Working Pressure (MAWP) and its relieving capacity must be equal to or greater than boiler output.

Shell:
The cylindrical portion of a pressure vessel.

Tube sheet:
The end plates with holes, in some boilers, that connects the ends of fire tubes.

Water tube:

A tube(s), in a boiler, having the water and steam on the inside and heat applied to the outside.

Water Softener:

Equipment used to remove the hardness from boiler feed water. A sodium zeolite water softener uses an ion exchange process to remove calcium and magnesium ions from water and replaces them with sodium. A brine solution and resin beads are part of the system which most water softeners use.

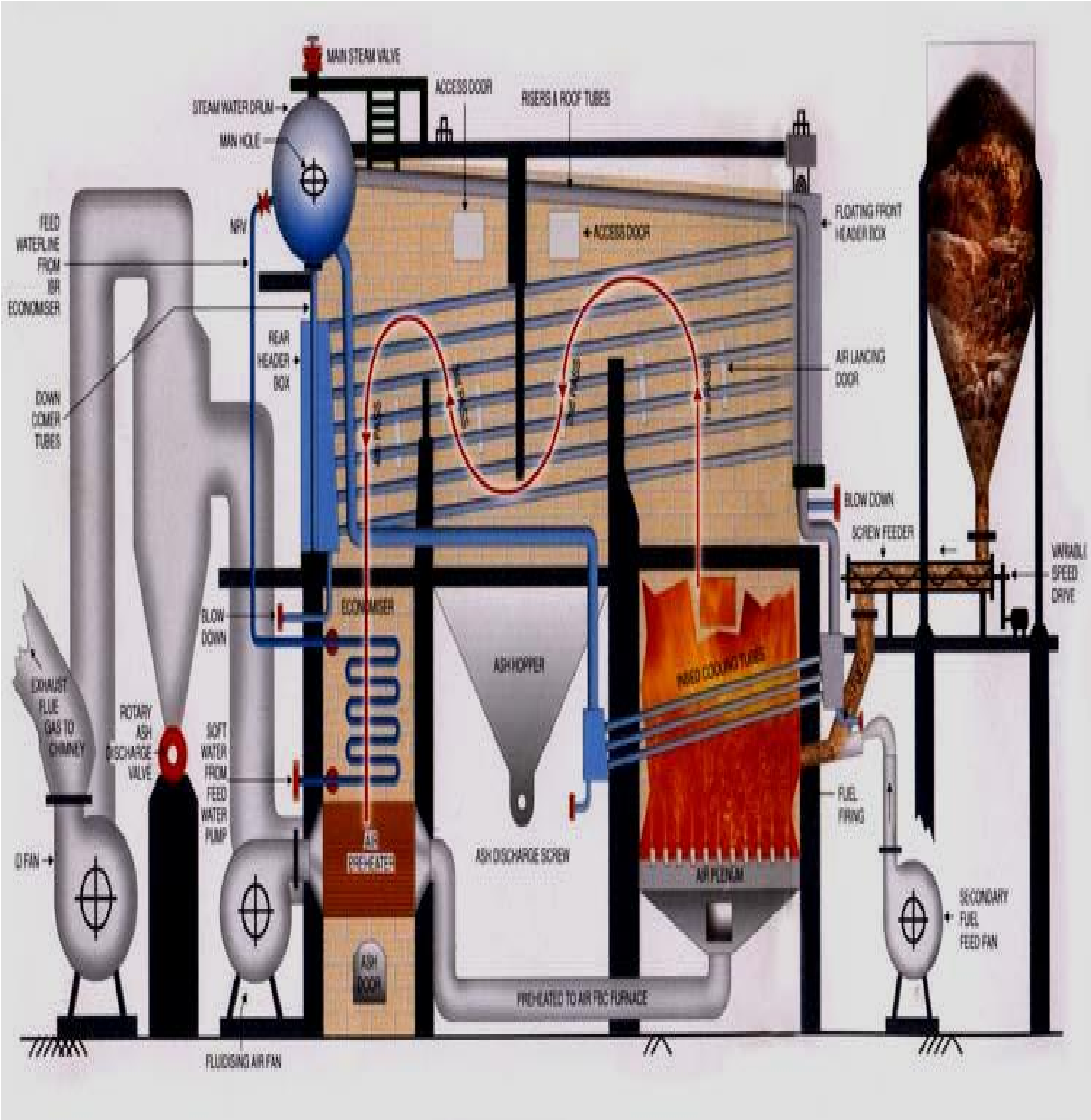

Fig.(4) HP Steam Boiler

2.2 REQUIREMENTS OF A GOOD BOILER

A good boiler must possess the following qualities:

1. The boiler should be capable to generate steam at the required pressure and quantity as quickly as possible with minimum fuel consumption.
2. The initial cost, installation cost and the maintenance cost should be as low as possible.
3. The boiler should be light in weight, and should occupy small floor area.

4. The boiler must be able to meet the fluctuating demands without pressure fluctuations.
5. All the parts of the boiler should be easily approachable for cleaning and inspection.
6. The boiler should have a minimum of joints to avoid leaks which may occur due to expansion and contraction.
7. The boiler should be erected at site within a reasonable time and with minimum labor.
8. The water and flue gas velocities should be high for high heat transfer rates with minimum pressure drop through the system.
9. There should be no deposition of mud and foreign materials on the inside surface and soot deposition on the outer surface of the heat transferring parts.
10. The boiler should conform to the safety regulations as laid down in the *Boiler Act.*

2.2.1 HIGH PRESSURE BOILERS

In all modern power plants, high pressure boilers (> 100 bar) are universally used as they offer the following advantages. In order to obtain efficient operation and high capacity, forced circulation of water through boiler tubes is found helpful.
I. The efficiency and the capacity of the plant can be increased as reduced quantity of steam is required for the same power generation if high pressure steam is used.
2. The forced circulation of water through boiler tubes provides freedom in the arrangement of furnace and water walls, in addition to the reduction in the heat exchange area.
3. The tendency of scale formation is reduced due to high velocity of water.
4. The danger of overheating is reduced as all the parts are uniformly heated.
5. The differential expansion is reduced due to uniform temperature and this reduces the possibility of gas and air leakages.

2.2.2 Combustion Control Systems

Regulates furnace fuel and air ratio within limits for continuous combustion and stable flame throughout the demand operating limits of the boiler and includes draft control.

The **fuel valve** maintains the fuel flow and the **air damper** maintains the air flow. The **jackshaft** is a shaft that drives the air damper and fuel valve on a power burner. The air damper and fuel valve are mechanically linked and the jackshaft simultaneously moves both to maintain the desired system pressure or temperature. .

A steam boiler is controlled by a pressure control (commonly called a **pressuretrol**), while a hot water boiler is controlled by a temperature switch called an **aquastat**. Boiler burners can be designed to operate the burner and steam production as an **'on-off' system**, which simply turns the burner on and off as load (demand) changes; or as a **modulating system**, which increases or decreases the burner firing rate as the load changes.

The boiler burner **primary control** is the device that safely manages the burner operation. Sometimes called the **programmer** or **burner management system**, the primary control allows fuel to flow only when all of the safe conditions for fuel ignition are met.

The sequence of burner operation does not allow fuel to flow unless all controls and safety devices agree that the burner can safely operate. Called '**permissive**', the safety controls include the **low water fuel cut-out (LWCO)**, the burner fan, high pressure or high temperature cut-out, fuel valves, gas pressure switches, etc. If all the permissive agree, the fuel valves will open as directed by the burner control. If any one of the permissive is not satisfied, fuel cannot flow, as the permissive are wired in a series circuit.

The **flame safeguard system** 'proves' flame in order to safely allow fuel to flow to the burner. There are five types of flame detectors when used with combustion heating equipment. They are:

1. CAD Cell (Cadmium Sulfide) the photocell changes resistance as cadmium sulfide is responsive to light
2. Infrared (IR) Light is sensitive to the infrared radiation emitted by the combustion of fuels such as natural gas, oil and coal.
3. Photocell sensors that detect visible light
4. Ultraviolet (UV) Light sensors that detect ultraviolet radiation emitted from all flames
5. Flame Rod is a sensor that has the ability to use a small amount of current, which is conducted by and through the flame.

2.3: Boiler Maintenance

2.3.1 Maintenance Basics

The **boiler operator** is responsible for operating and maintaining the boiler in a safe and efficient manner through the use of sound engineering practices and manufacturer's specified maintenance procedures. Most boiler accidents are caused by operator error and poor maintenance.

The **Chief Engineer** of a boiler plant holds the responsibility for directing boiler operations, procedures and maintenance. The information used by the Chief Engineer comes from manufacturer's recommendations.

Log sheets are a paper record of boiler operation and maintenance, and should be used in all boiler rooms to help ensure safe operation. A log sheet will specify the task to be performed, such as blowing down the low water cut-out (LWCO), and the operator can then mark the sheet to show that this operation was completed. General Boiler Operations include:

• **Startup** - Cold iron start up and new plant start up. Most furnace explosions occur during start up and when switching fuels, so always follow the manufacturer's guidelines.

• **Operation & General Maintenance:**

– requires proper training, equipment familiarity and routine maintenance procedures

• **Shutdown** – Whether for a short time or long time, different procedures exist. If the boiler is to be placed out of service for an extended period of time, proper lay-up procedures are required and must be followed.

Normal Operating Water Level

The most important task in boiler maintenance is maintaining the **normal operating water level (NOWL)** in the boiler. A low water condition is the most common cause of boiler failure. The first thing a boiler operator should do when entering the boiler room or taking over boiler operation is to check the NOWL. An **automatic boiler feed water regulator** is designed to maintain the proper water level in the boiler. A **low water alarm** in the system is designed to alert the boiler operator of a low water level. In the event of a low water alarm, secure the fire first before adding water to the boiler. The **gage glass** (sight glass) is a tube that indicates the water level in the boiler. It is installed either directly on the boiler or on the water column. It is connected at the top into the steam section of the boiler and at the bottom into the water section, thus showing the true boiler water level. The water level in the gage glass is tested by opening and then closing

the gauge glass blow down valve. In addition to the gage glass, some boilers also have **try-cocks** installed to indicate the water level. The three try-cocks (which are draining valves) are placed on the water column at various levels. If the boiler water level is at the NOWL, the bottom try-cock will vent water, the middle try-cock will vent water/steam, and the top try-cock will vent steam.

Blow down.

The water removed under pressure, from a boiler, through the bottom drain valve(s), to eliminate sediment and reduce total solids. **Note**: Blow down of

Float-operated low water fuel cut-offs is also done for this reason. If sludge accumulates and builds up under the float the device may not be able to see an actual low water condition to shut off the burner.

Boiler blow down

is removal of water from the boiler. It is done in order to remove the amount of solids in the water, and is performed as either bottom (sludge) blow down, or continuous (surface) blow down. The blow down frequency and duration is primarily determined by the boiler water analysis. The water quality will vary greatly based on boiler type and size, amount of condensate return, and boiler water treatment program.

Inspections:

A boiler **internal inspection** is performed to allow the boiler inspection a view of all internal surfaces, i.e. tubes, shell, drum, welds, refractory, etc. The boiler is taken off line, cooled, drained, opened and cleaned in preparation for the internal boiler inspection. All hand holes and manholes are opened, and the low water cut-outs are opened and cleaned.

An **external inspection** can be performed by

- Viewing the outside of the boiler while operating
- Viewing the outside of the boiler while shut down but not open
- Hydrostatic inspection or Operational inspection which is performed while the boiler is on line. This is a water pressure test of new installations and repaired boilers. A **hand hole** provides access to the waterside of the fire tube boiler for inspection.

2.3.2 Boiler trim, Valves, Fittings, and Controls:

Boiler trim is the controls and fittings used to operate the boiler. The trim determines whether the pressure vessel is used for steam or hot water production. Trim includes devices such as the low water cut-out, the gage glass (sometimes called the sight glass), the pressure gauge, etc.

Valves:

The **safety valve** (also referred to a relief valve, pop-off valve, or safety relief valve) provides protection to the pressure vessel from over pressurization and is the primary safety control on all boilers. Safety valves are designed and installed in accordance with ASME and NBIC code. They must be of sufficient size (capacity) to keep the boiler from developing more steam pressure than the valve can relieve, and must be set at or below the boiler MAWP (Maximum Allowable Working Pressure). Valve pressure settings cannot be changed by plant personnel, but must be calibrated by a certified repair facility. There should be no shut off valves between the boiler and the pop-off valve. Boilers with more than 500 sq ft. of heating surface require two or more safety valves.

Safety valves are spring loaded valves and should be regularly tested by the boiler operator on duty, unless plant policy states otherwise. Testing a safety (relief) valve is performed by simply lifting the test lever on the side of the valve. This test is done while the boiler is operating at between 75% and 100% of its operating pressure. Prior to the test, determine that the valve discharge is piped to a safe place.

A **gate valve:**

is an isolation valve, and is used only for the purpose of stopping or allowing flow. Gate valves are used as steam stop valves, blow down valves, etc. Gate valves should always be fully open or completely closed, never in between.
An **Outside Stem and Yoke or OS&Y valve** is a gate valve designed for boiler room service. The stem and yoke are outside the valve body. A rising stem valve allows the boiler operator to know the position of the valve by looking at the stem. If the stem is extended (up or out) the valve is open. In an open position, the valve provides no resistance to the flow of steam. If the stem is down or in, the valve is closed. These valves are typically seen in steam lines.

A **globe valve:**

is a modulation valve, not an isolation valve. A globe valve disrupts the flow of the fluid, even in the fully open position.
A **check valve** allows flow in one direction only. These are often seen in feed water lines between the pumps and the boiler. When opening any manual valve, the boiler operator should open the valve slowly in order to prevent water hammer.

Low Water Fuel Cut-Out (LWCO*)* the **LWCO:**

is designed to protect the boiler from a low-water condition. The control opens the burner circuit, stopping the burner if it senses a low-water level. An LWCO that controls only the burner circuit (such as the secondary LWCO on a steam boiler) is called a **single element control**. Controls may also operate the feed water pump or valve or a make-up water valve as well as the burner. They are called **dual or triple element controls**. If the LWCO is mechanical (a float), it must be blown down (drained) on a regular basis to prevent sediment from accumulating in the float chamber. If it is electronic, this procedure is not necessary. Both types should be disassembled and cleaned at least once per year.
Testing the LWCO is done by draining the float chamber to see if the burner stops, called a **controlled blow down test**. This test should be

performed on a regular basis. The electronic control is tested by the evaporation or slow drain method. This test requires the feed water supply to be secured, and the burner is allowed to operate normally. If the control is functioning properly the burner will shut off when the water level goes below the NOWL. As the water supply has been shut off to the boiler, this test is extremely dangerous and should only be done by qualified operators.

2.3.3 Boiler Water Treatment

There are three phases of water treatment in a boiler system:

- **Blow down**, which maintains the TDS (total dissolved solids) in the system
- **External Treatment**, which removes hard salts, minerals and oxygen before the water enters the boiler
- **Internal Treatment**, which maintains proper water chemistry by adding chemical additives to the boiler water

The primary goal of boiler water treatment is to control solids that cause deposits in the boiler and control gases that cause corrosion.

The boiler **feed water system** includes the necessary equipment to supply the boiler with the heated / treated water for maximum boiler efficiency. A **feed water pump** pumps the water from the feed water system to the boiler.

Hardness & Scale City and well water supply contains minerals and solids**. Calcium** and **magnesium** are the most common of the minerals found in water supplies. Water may also contain silica, iron, and other trace minerals that vary by geographic location. The build up of minerals on a surface is referred to as **scale**. The build up of scale on a heating surface insulates and overheats metal surfaces, reducing the life of the boiler and making it less efficient. Additionally, the scale can travel downstream of the boiler clogging ports and surfaces of other equipment.

Hardness of water is the measurement of mineral content or scale forming salts in water. **Hard water** is water than contains more than 25 ppm of scale-forming minerals. **Soft Water** is water with low mineral content.

Conductivity:

is a measurement of how many solids are in the water, based on the conductance (ability to conduct electricity) of the water. The more solids, the better the water conducts electricity and the more scale will build up. Water treatment programs use conductivity as a way to measure and control the solids level in the boiler water. The water treatment program should specify the maximum amount of conductivity allowed in the boiler water. Conductivity is controlled by blow down.

Water can be softened by the use of a **water softener** (sodium zeolite) that removes hardness minerals before the water enters the boiler, or softened chemically while the water is in the boiler. Most boiler plants in hard water locations use both methods to ensure hardness removal.

Phosphates (tri-sodium phosphate, dipotassium phosphate), chelants, and polymers are used for steam boiler scale and corrosion inhibitors. **Sodium nitrite** and **sodium molybdate** are used as inhibitors in hot water systems.

In addition, boiler water treatment compounds usually contain **tannins** and **lignins** for settling and dispersal of sediment in order to prevent the sludge from adhering to the boiler surfaces.

PH, the potential of Hydrogen ions, is a measurement of the acidity or basicity of the water. The pH scale runs from 0 –14, with the low end being acid and the high end being base. Untreated ground or surface water is usually in the pH range of 6 – 8. Ideal water pH for boilers will range from 8 pH to 12.7 pH, depending on the type of boiler, so the pH level of the water sometimes needs to be increased. **Sodium hydroxide** (caustic soda) and **sodium carbonate** are often used to raise the pH of the boiler water in steam systems, while **sodium borate** is commonly used in hot water boilers.

Gases:

Steel boilers are prone to attack from the oxygen in the boiler water, which causes pitting, a severe form of corrosion. Pitting damage is irreversible. As the water is heated, gases (oxygen and carbon dioxide) are driven out of the water and settles on the metal surface, causing a corrosion cell. Water treatment programs minimize the damage caused by water as it contacts the boiler metal. Oxygen can be removed mechanically using a deaerator, and chemically (scavenged) with such compounds a sodium sulfite, bisulfite, and hydrazine. High pressure boiler plants typically utilize a deaerator followed by addition of chemicals to the boiler water, while low-pressure plants generally use only the chemical method of oxygen scavenging.

Volatile amines:

of either the filming or neutralizing type, are used for prevent of pitting and corrosion in steam and condensate return lines.

Carryover:

is the term used to describe water being carried with the steam into the steam system. Carryover can lead to water hammer and wet steam.

Water Hammer:

occurs when water is being pushed through the steam lines by the steam. This can result in damage to the system piping, valves, and fittings.

Wet steam

is water droplets being contained within the steam. Wet steam may not cause problems in low pressure systems, but can cause serious damage to high pressure turbines.
Carryover can be caused by several factors, including higher than normal water level surface and impurities such as oil or foam.

2.4 Boiler Efficiency

The efficiency of the burner determines the amount of heat being lost in the combustion process. **Burner efficiency** is calculated by obtaining a flue gas sample and analyzing the by-products of combustion, such as carbon dioxide, oxygen, carbon monoxide, nitric oxide, sulfur dioxides, etc. and comparing those readings to the stack temperature.

Boiler efficiency

includes not just the burner, but the entire heat exchange process. Boiler efficiency is a calculation of the amount of heat content (in Btu) purchased in the fuel compared to the heat of the steam (in pounds) that is produced.
Total boiler efficiency includes radiation and convection losses as well as combustion loss.
The biggest problem in boiler efficiency is poor waterside care, which leads to scale and corrosion of the heat exchange surfaces. Poor care of the fireside (mainly when burning oil), and loss of heat through un-insulated or poorly insulated surfaces are also big sources of efficiency losses, but not as significant as waterside losses.
A regular **burner checkup** and tuning will maximize combustion efficiency. The burner technician will maximize CO_2 while Minimizing O_2, and maintain as low as possible stack temperature.

Condensate:

is steam that has given up its heat and should be returning to the boiler. Lost condensate is lost money, as the water has been purchased, heated, and chemically treated, all costing money. Returning the condensate to the boiler instead of dumping it to a drain can save thousands of dollars per year.The **steam trap** is designed to hold steam in the piping or heat exchanger until it has given up its latent heat. When this has occurred, the

steam will condense, or change state back to a liquid. The steam trap will let condensate pass through, but will not allow steam to pass.
There are several types of steam traps. All are designed with the same goal: allow condensate, but not steam, to pass through the trap.
The **inverted bucket steam trap** consists of a bucket that will rise when steam enters the trap, blocking the discharge. As the steam cools and condenses, the bucket falls, allowing the condensate to pass.
The **float and thermostatic (F&T) trap** has a float that rises when condensate enters the trap, opening the discharge. The thermostatic element allows air to vent, but closes when steam enters the trap. The thermostatic trap uses a bellows filled with fluid that expands when the steam enters the trap, closing the discharge.
An **economizer** is installed in the stack of some boilers. The economizer saves energy by using heat that would otherwise be lost to the atmosphere. The economizer is a heat exchanger that pre-heats the boiler feed water with heat from the flue gases. Flue gases can also be used to heat the combustion air being brought into the burner**.**

2.5 REQUIREMENTS

Minimum requirements that Criterion users shall follow are specified in this section.
The Criterion users are responsible for analysis of operational performance and SSC replacement or refurbishment based on their analysis. Laws, codes, contractual requirements, engineering judgment, safety matters, and operations and maintenance experience drive the requirements contained in this section.

Operations Requirements:

When starting a boiler, after lay-up, bring pressure and temperature up **slowly**. Stand by boiler until it reaches the established cutout point to make sure the operating control shuts off the boiler. During this period, walk around the boiler frequently to observe that all associated equipment is operating properly. Visually check burner for proper combustion.

Maintenance Requirements:

Listed below are frequencies for the various routines and tests that shall be performed in connection with the inspection and maintenance of steam /hot water heating boilers.
1) **For daily**; it is recommended that building managers, or their designees, check operating boilers daily, in their buildings, during the workweek. Observe water levels, operating pressures, temperatures and

general conditions. Determine the cause of any deviation from expected values, unusual odors, noises, or conditions.

2) Weekly (Steam Boilers in Service Only)

• Observe water level at the gage glass, operating pressure, and condition of flame and general conditions. Blow down water column, in gage glass, through the gage glass blow down valve. This action keeps the water column and piping connections clean and free of sediment or sludge.

• Test the two float-operated low water fuel cut-offs (LWC) by blowing them down, one at a time, while boiler is firing and under pressure. This action not only flushes out any sludge that might accumulate under the float but it also simulates a low water condition, by tripping the mercury switch in the LWC, turning off the burner. It is crucial that the burner turns off immediately during these tests.

• Bottom blow down.

• Observe condition of condensate feed pump.

• Test boiler water for proper chemical levels. The chemical levels are recommended by the water treatment vendor.

Note: Additional water treatment may be required on some steam boilers. As an example, the 100% make-up water required for the high-pressure “process” steam boilers at TA 55-6 is first pretreated by passing the makeup water through a water softener and then preheated in a deaerator. In this particular system the condensate in not returned to the boilers.

3) Semi-Annually

• Observe water level and operating pressure in steam boilers or temperature and operating pressure in hot water heating boilers and general conditions. Fire and cycle boiler. The burner should start smoothly without unusual noises. Visually inspect combustion. Changes in flame shape, color and sound are among early indicators of potential combustion-related problems. Changes may be due to changes in fuel pressure or gas/air linkage movement. Check gas/air linkages, on power burner that modulate, for positioning, tightness and binding. Combustion analysis is verifiable only with a flue gas analyzer and is performed mainly on boilers with power burners.

• Inspect fuel supply system and gas controls. Leak check gas controls and associated gas piping with a gas detector or soap suds.

• Test float-operated low water fuel cut-off (LWC) by blowing it down while the boiler is firing and under pressure. Steam boilers, unlike hot water heating boilers, have two of these devices. This procedure not only flushes-out any sludge that might accumulate under the float but it also simulates a low water condition, by tripping the mercury switch in the LWC, turning off the burner. **Note:** On hot water heating boilers it may be necessary to trip the float assembly linkage manually, after blowing down the LWC, to make the mercury switch trip. This is done because a hot water boiler is full of water and will not always trip the mercury switch in the LWC, like a steam boiler will, when the LWC is blown down. Remove the cover on top of the LWC to access the float assembly linkage. It is crucial that the burner shuts off immediately after these tests.

• Test safety/safety relief valve. (Try Lever Test) Manually open the valve by lifting up on the handle while boiler is under pressure. Water or steam should flow when this is done and should shut off completely when the handle is released. Some boilers have two of these devices.

Note: The discharge from these valves is under pressure and is at high temperatures. Exercise caution to avoid personnel injury or injury to others.

• Observe the operation of operating control. Operating controls start, stop and modulate some burners (if desired) in response to the systems demand, keeping steam pressure or hot water temperature at or below controller setting.

• Test limits control.

• Test flame detection devices on boilers with flame scanners. Remove the flame scanner with the burner firing. The burner should shut off as a flame failure condition. Clean the flame scanner, reinstall and reset programmer. Check for proper operation as boiler goes through a firing cycle and light off.

• Check all electrical controls and circuitry. Careful inspection may disclose any of the following items: cracked mercury tubes, separation of mercury, cracked insulators, jumpered conditions, loose connections, poor or deteriorated wiring and foreign matter.

• Observe condition of condensate or expansion tank. A waterlogged expansion tank will cause the safety relief valve, on a hot water heating boiler, to relieve every time that it fires. This causes the introduction of makeup water, causing a dilution of the water chemistry in a treated system. Drain expansion tank if it is of a non-bladder type and refill to reestablish an air cushion.

• Observe operation of condensate or circulating pumps. Lubricate pump motors if they are of the type that needs lubrication.

• Observe operation of forced draft fan motors on boilers with power burners and induced draft fan motors on horizontal breeching where applicable.

4) Annually

i)Waterside Preventative Maintenance (All Steam Boilers)

• Lockout/Tag out boiler and shut-off gas supply.

• On most steam boilers with power burners swing open front and rear flue doors.

Inspect tube sheets for water leakage. The narrow ligaments between tube holes are subject to tremendous stresses and should be watched for any sign of cracking mainly due to overheating.

• Drain steam boiler and remove all hand hole and manhole covers, where applicable, to allow a visual check of all internal accessible areas. Example: shell, tubes and tube sheets

• Carefully examine waterside surfaces using a strong light and mirror where required. Look for evidence of scale, corrosion, blisters, or pitting, indicating adequacy of water treatment.

• Use a high-pressure hose to wash sediment out of the bottom and other internals of the boiler.

• Remove heads from the bodies of the float-operated low water fuel cut-offs (LWC). The float-assembly and mercury switches are located on these heads..

• On steam boilers remove pigtail loops from between boiler and pressure control devices. Clean and reinstall.

ii) Fireside Preventative Maintenance (Steam/Selected Hot Water Boilers).

Note: These selected hot water boilers are mainly boilers with power burners that have refractory in front and rear flue doors or have heat extractors in the fire tubes as are found in most one-pass boilers .Steam and hot water heating boilers with atmospheric burners generally require minimal fireside preventative maintenance.

• Routine burner maintenance. Check gas burners for presence of dirt, lint, or foreign matter. Be sure ports, gas passages and air passages are free of obstructions. Check gas/air linkages and moving parts on power burners that modulate, for positioning, tightness and binding. Also check pilot burners and ignition equipment for proper condition and adjustment.

• Check the fireside of furnace and fire tubes for any evidence of soot formation or corrosion. Evidence of soot formation is a sign of improperly adjusted combustion. Brush and vacuum furnace and fire tubes if such conditions exist.

On one-pass boilers, if in place, check condition of all heat extractors. These devices can be pulled out individually from each of the fire tubes and cleaned if necessary. Check refractory materials, if in place. Repair or replace if necessary.

• Check flue door gaskets and other gaskets to make sure that they are in good condition and that they are properly secured. Replace if necessary. An ineffective seal may allow flue gases to escape into the boiler room and result in burned gaskets and warped flue doors.

• After the fireside and waterside surfaces have been inspected and work completed, close flue doors and re-install handhold and man hold covers if applicable. Hook up all associated piping and refill boiler. Fire-up boiler and check for air, gas and water leaks.