CHAPTER - 13
Design Fundamentals of Boiler

In a steam generating unit two distinct fundamental processes take place:
1. Conversion of the chemical energy of the fuel into thermal energy
2. Transfer of this liberated thermal energy to the working fluid to generate steam for useful purpose(s).

This being the case, the basic task of a boiler designer is to maximise the output of these two processes simultaneously. Heat can only flow from higher temperature to lower temperature and as such the designer must design the layout of the entire heat-absorbing surface in such a manner that it will receive maximum available heat in the process of fuel combustion.

Boiler design is an extremely specialized subject. In practical terms, the designers face various processes of heat transfer due to constant variations of operating parameters, changes in the configuration and cleanliness of heating surfaces. Finally, there is another paramount task of obtaining maximum efficiency at lowest cost. For this, all component parts must be properly designed and accurately proportioned and linked to the other elements with each process being correctly assessed and related to the other processes involved in the unit as a whole.

Boiler Development through the years:

When steam was first used for power purposes the boiler and engine were encased into one piece of plant.

Example of this in use today is steaming locomotive.

Because of increase in power requirements, it soon became evident that it would be better to have separate steam boiler in which heat could be generated.

Development of steam boilers:

When water is converted into steam it is termed as evaporation.

Large rates of evaporation take place in modern boilers say up to 3000 tonnes/hour.

At first boiler was simply a tank in which water was heated and evaporated at about atmospheric pressure.

Addition of auxiliary equipment enabled boiler to be safe and economical.

Boiler Classification:

Boilers are classified as either shell type or a shell and fire tube or water tube type.

1. The Shell type boiler is one in which firing equipment is placed bellow the shell or in a large diameter flue pipe and gases made to flow in one or multiple passes.
2. The shell and fire tube boiler is one in which the heated gases pass through the tubes that are surrounded by water.
3. The water tube boiler is one in which water that is to be heated is passed through the tubes that are surrounded by hot gases.

Essential Equipments with a Boiler:

Essential Equipments those are Common to all types of Boilers are as follows:

1. Water / steam vessel capable of withstanding the pressure for which the boiler designed.
2. Safety valves to prevent excessive pressure
3. A gauge for indicating pressure
4. The vessel must only be partly filled with water in order to leave space the steam generated.
5. The Water gauge glass to show water level of the boiler.
6. A pipe to remove the steam generated, which must be fitted with a stop valve.
7. A pipe fitted to introduce the water in to the boiler to replace, that which has been evaporated thus keeping the water level constant.
8. A blow down pipe to remove sediments that is carried with the water
9. An adequate amount of drum internals or internal water surface area so that the bubbles rising from water surface do not carry water particles along with them into the steam outlet thus causing what is called ‘ priming’.
10. Since stagnant water is bad conductor of heat, it is necessary to ensure that heat from the furnace is readily conveyed to the steam-water mixture by good circulation.
    It can be demonstrated by heating water filled test tube at the top and making the water at the top boil but ice held at the bottom not melting for long time. Adding color pieces at the bottom of the test tube and heating it from the bottom will show the starting of convection current.
11. Some means for feed air and fuel to burn fuel and release heat, and remove products of combustion.

Fire Tube & Water Tube Boiler:

In a fire tube boiler burning of fuel is carried out in the flue tube of large dimensions surrounded by water on its outer side. In a water tube boiler this is carried out in a furnace.

Development of Multi-flue Boiler:

For a given material required tube or pipe thickness is proportional to pressure and diameter and inversely proportional to the permissible stress. On oil /gas fired boilers, increase in evaporation beyond 12 tonnes/hours requires larger diameter flue tube and corresponding increase in thickness of the flue pipe that could not be effectively cooled by convective currents induced in a flue pipe boiler.
It lead to development of boilers having more than one smaller flue i.e. multi-flue boiler.

Development of Water Tube Boilers:

Increase in evaporation required more heating surface and corresponding increase in shell diameter surrounding the increased number of externally water cooled flue tubes. It made larger and high-pressure fire tube boilers uneconomical and lead to development of large water tube boilers.

It follows that smaller diameter tubes can withstand higher pressures without requiring excessive thickness and are therefore not unduly costly.
Increase in the required steam pressure also posed similar problem of too thick flue pipe. That is why Water tube boilers became essential for higher pressures, temperature and rates of evaporation.

Furnace Development on Flue Tube Boilers:
Earlier external refractory furnaces required considerable maintenance and having cooled metallic surface inside the furnace was desirable.
In flue tube boilers, gases leaving boiler furnace flue were still very hot and required protection of end plates by refractory. It was an annual maintenance item. Such boilers were sub-classified as **dry back** type flue tube boilers.
In some of the new designs of highly rated flue tube boilers, an additional water-cooled partial end chamber was added to eliminate the refractory on the back plate of end plate. Such designs are called **wet back** flue tube boilers and have become popular on highly rated marine boilers.
Furnace Development on Water Tube Boilers:
Need to decrease maintenance and furnace infiltration led to Cast Iron lined Bailey wall blocks with water wall tubes behind them-an idea used in glass industrial furnace.
Then came the spaced water cooled walls backed by refractory and ultimately the fully water-cooled walls of modern design.

Water Wall Development:
It followed the route:-
1. Refractory wall
2. Water wall tubes backed by refractory
3. Tangent Tube construction
4. Spaced tubes with flat studded fins
5. Membrane wall with flats welded between space.
6. The cooling effect of water walls lowers overall gas temperatures. As a result less slag is formed. Slag is the result of the melting of ash particles which when partly cooled becomes sticky mixture and clings to the wall surface.

Design of Water Tube Boilers:
Diameter of tubes is kept as small as possible for subject to adequate water circulation.
Because of larger heating surface exposed, a higher evaporation rate was possible.
In place of copper, Steels with higher carbon content (from 0.1 to 0.3% C) was used for higher strength. Only limitation was weldability.
Welded tube construction, metallurgical developments, construction overcoming problems of metal expansion by top suspension supporting methods, development of buckstays and tie-bars enabled large and tall boilers for higher capacity and higher temperatures to be built.
For better performance Water walls and circulation systems were developed. In earlier designs, heat-resisting material called refractory was used. Very often refractory work deteriorated very rapidly due to the

severe heat conditions in the chamber leading resorting to lowering rating, higher excess air and inefficient operation and plant outage for repairs and labour costs. Water walls are now extensively used with proper circulating systems which was discussed in detail under the chapter on "Circulation System"

Various factors for the design consideration of a boiler

Service requirements:

It implies the nature of service it will render, i.e. whether the unit will be for a public utility central station for production of electricity or for an industrial plant for the generation of steam and or electricity for process use.

The industrial plant works under more unfavourable conditions of load, water and fuel than the central power station steam generator. The steam load in an industrial plant may be highly unpredictable, changing between high and low extremes.

Load characteristics:

The boiler must be so designed as to run at high efficiency under most often occurring load and at the same time should be capable of meeting maximum demand as well as fluctuating load characteristics. Hence the boiler designer should essentially consider the following load characteristics:

a. Maximum load, normal load and minimum load
b. Load factor
c. Nature of load – constant or fluctuating
d. Duration time of each load rate.

Fuel characteristics

From these very characteristics, a boiler designer gets the knowledge of the heat value available from the fuel as well as its specific properties such as:

(a) Proximate analysis and ultimate analysis giving C, H, S, N, O
(b) Moisture and ash %, % of volatile matter and fixed carbon %
(c) Nature of ash and its initial deformation temperature, hemispherical temperature and fluid temperature point.
(d) The presence of such corrosive agents as sulphur, Na and vanadium that will dictate the flue gas exit temperature as well as the material of construction of the heating surface of the SH to avoid the problem of corrosion and slagging.

Proximate analysis indicates the fuel ignition and burning characteristics of fuel, which in turn influence firing method and the boiler design.

Mode of fuel burning:

The mode of fuel burning exert an influence upon boiler design because it is the capacity of the fuel burning device that controls the rate of fuel input which in turn determines the furnace cross section, volume and its design specifications.

The design of pulverised coal fired boilers is certainly not the same as stoker or grate fired boilers.

Be it oil fired burners of – vapourizing, rotary, gun or steam (or air) atomizing type – or gas fired burners, each type dictates its own design peculiarities on the design of the boiler furnace. As the furnace design undergoes a change, so does the layout of the heat absorbing surface of the boiler.
However, it can be safely concluded that the type of fuel burning equipment and the method of firing exercise much greater influence on furnace design and consequently on boiler design.

Hydrodynamics of gas flow:
The gas flow through the boiler is affected by the differential pressure between the combustion products in the furnace core and the flue gases at the boiler exit. This pressure difference, called draught (draft) may be affected by natural means or by mechanical means such as induced draught fan. To supply the necessary primary and secondary air to sustain and control fuel combustion, forced draught fans are provided.
Depending upon whether this draught is produced by natural or induced (by chimney effect) or by mechanical means (by installing induced draught fans, forced draught or both), the boiler design is altered accordingly. The quantity of excess air supplied in the form of primary/secondary air influences the boiler capacity as well as furnace temperature.
If the firing rates are high, the draught requirements and resultant flue gas flow rates will be considerably very large and accordingly, the size of the ID and FD fans becomes proportionately much bigger and it necessitates increase in the size of the boiler unit.
Again, for higher boiler efficiency, one needs to extract as much heat as possible from flue gas and combustion air to be preheated and therefore, an air preheater is to be installed almost invariably in the convective path of the boiler. And that means a further draft loss which must be taken into account in the overall design of the induced draft and forced draft fans.

Feedwater quality:
The presence of dissolved solids and gases, suspended matter and organic contaminants in feedwater cause corrosion, priming and foaming that effectively impair the performance of a boiler. These undesirable ingredients must be eliminated as much as possible before the feedwater is charged to the boiler. Quality requirements become more stringent with the increase of pressure and temperature of generated steam.
Feedwater quality, together with required steam quality, operating pressure and of other factors, influences the design of drum internals, steam separators. Very high pressure operation require steam washer to avoid excessive silica carryover in steam.

Furnace size, shape and material of construction:
The furnace volume must be sufficient to maintain the necessary heat release rate and furnace exit gas temperature while the combustion space should be sufficient to contain the flame so that it does not directly hit the waterwalls.
The rate of steam generation and the temperature and pressure of superheater and reheater steam dictate the gas temperature at the inlet of

superheater and the heat release rate govern the size and shape of the furnace, nature and materials of construction of furnace wall and disposition of heat-absorbing surface in the radiant and convective shafts of the furnace

Type of furnace bottom:

Furnace bottom design becomes an essential consideration during designing coal fired boilers. They may be pulverised coal fired or stoker or grate fired. In each case, the removal of ash and slag poses a problem. For pulverised coal firing, the furnace bottom must be cone shaped to drop out all solidified slag and ash to be carried off mechanically, pneumatically or by water. In the case of stoker fired boilers due to lack of proper furnace design, another ash removal arrangement may result in excessive slagging of waterwalls impairing the heat transfer characteristics and performance of the boiler.

Boiler proper:

Factors that control the design of the boiler proper are:

a) The operating pressure and temperature.
b) The quality of steam – Whether the steam required should be wet, dry or superheated. If wet steam is required, the designer may do away with the separator and superheaters. If 99.5% dry steam is required, the designer must opt for suitable steam separator. The incorporation of a superheater or reheater becomes obvious for obtaining superheated steam or steam reheating to high temperature to return from outlet of high pressure portion of the turbine.
c) Layout of heating surface – The prime aim of the boiler designer is to obtain the best disposal of heat-absorbing surface within the limitations of space as dictated by the furnace and other components.
d) Heating surface requirements – These depend upon the duty of the element heat exchangers such as primary evaporators, secondary evaporators, superheaters – radiant and convective, reheater, economiser and air preheater.
e) Circulation of steam and water – natural or forced.
f) Provision for continuous blowdown.
g) The capacity of boiler drum.
h) Materials and methods of construction.

Boiler Operation:

Boiler operation and maintenance is considered to be essential elements in boiler design because the life of a boiler is extended with good, trouble-free operation and adequate maintenance and cleaning. The designer must make arrangement for efficient removal of:

a. Soot, slag and ash deposited on the fire-side of heating surfaces
b. Scale, sludge and silt settled on the water-side of heating surfaces.

Accessibility for operation, maintenance and repairing must be easy and quick to ensure higher availability and offset the long outage time.

Adequate provision must be made for:

a. Soot blowing
b. Tube cleaning – chemically and or mechanically

c. Washing economiser and air preheater surfaces.

Automation should be injected wherever it leads to higher reliability and greater ease in boiler operation.

Capital investment:

The factors involved in determining the overall capital investment in designing a boiler are:

a. Cost of equipment.
b. Cost of fuel.
c. Cost of labour and materials for operation, maintenance and repairing.
d. Cost of the auxiliaries, e.g. cost of running pumps, fans, ash disposal systems, etc.
e. Expected life of the equipment.

Classification of Utility and Industrial Boilers:

The utility boilers are large capacity steam generators used purely for the electrical power generation. The industrial boilers are mainly for use in the process industries and are characterized as follows:

a. Non-reheat units.
b. Bi-drum boilers having partial steam generation in the boiler bank tubes.

Though the physical arrangement and location of various heat transfer sections may differ considerably, the general design criteria from the performance aspect does not change much for the two classifications.

The various heat transfer sections of a boiler can be grouped as follows:

UTILITY	INDUSTRIAL
Furnace (water cooled)	Furnace (water cooled)
Superheater	Superheater
Reheater	Boiler Bank
Economiser	Economizer (may or may not be used depending on feed water)
Airheater (will generally be required to provide hot air for P.F. fire jobs)	Airheater (may or may not be used)

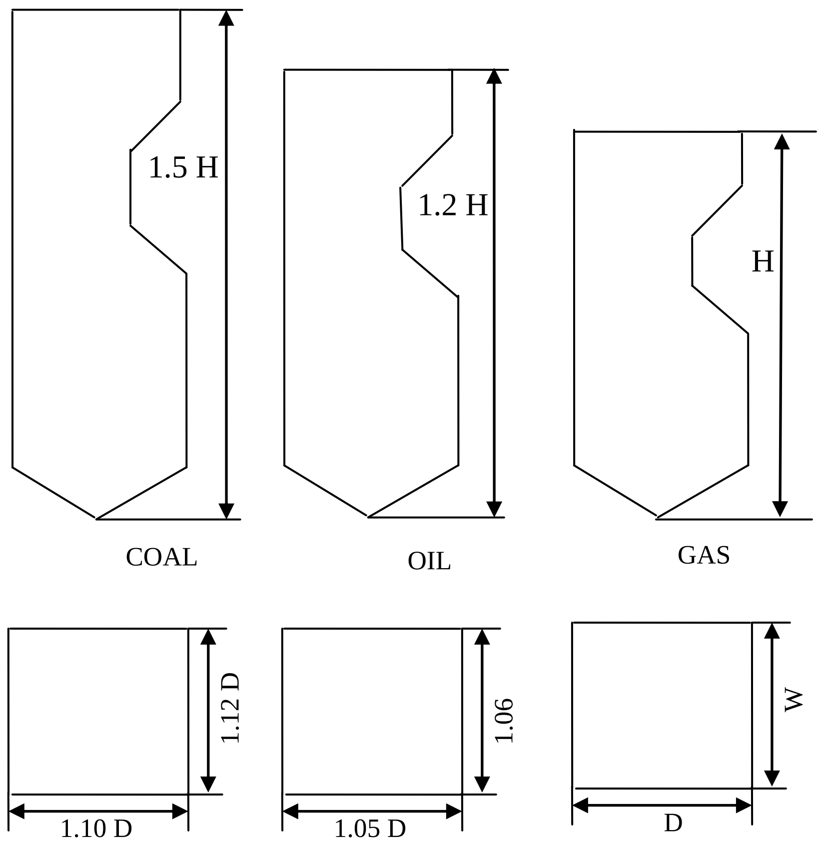
The design aspects of these sections are discussed further.

Furnace:

The furnace design is influenced by the following factors:

a. Quantity of Fuel fired and type of fuel
b. Allowable heat loading in furnace
    i. Effective Projected Radiant Surface (EPRS)
    ii. Plan area
    iii. Volumetric
c. Burner clearance
d. Arrangement of pressure parts

Effect of fuels on furnace design:
The major fuels used in the steam generators are coal, oil and gas. The furnaces designed or firing pulverized fuels are basically sized to ensure complete combustion with minimum formation of objectionable slag deposits. For coal fired boilers this requirement generally results in a relatively low furnace wall absorption rates with safe metal temperatures.
In the oil fired boilers, the combustion can be achieved in a much smaller volume of furnace than a coal fired unit. However this intense combustion process results in very high localized heat absorption rates, the furnaces selected for oil firing are increased in size above the minimum required to complete combustion only, to a size that will produce safe furnace wall temperatures.
The combustion characteristics of gas produce a more uniform heat release pattern within the furnace. This allows the use of even smaller furnaces than for oil.



The figure above illustrates the relative size of units designed for these three fuels.
All coals have certain characteristics (Table 1) which may be used on a relative basis to compare their effect on furnace sizing.

Table 1: Coal Characteristics:

Total moisture	15 %
Ash	30 %
Sulphur	0.50 %

HHV	4500 K.Cal/Kg.
Ash softening temperature (at reducing atmosphere)	1250°C
Sodium content in ash as Na_2O	01

The moisture content in coal affects the design of the boiler in many ways such as combustion gas weight, flue gas velocities, boiler efficiency, heat transfer rates and low temperature corrosion.

The ash quantity and quality can affect the furnace slagging rate, fouling of superheater, reheater and air heater surfaces, the unburned carbon loss, the amount of particulate emission discharged to the atmosphere and the capacity of ash handling system.

Allowable heat loading:

The furnace heat loading is a characteristic requirement for each fuel. Normally 3 basic heat loading is considered for furnace design.

The EPRS (Effective Projected Radiant Surface) heat loading can be related to the gas temperature leaving the furnace. This value changes from 200,000 to 325,000 K.Cal/hr/m^2 for coal fired boilers and reach a maximum of 550,000 K.Cal/hr/m^2 for oil and gas fired boilers. This gas temperature is very much significant in the case of coal fired boilers. This value should be considerably lower than the initial ash deformation temperature to protect superheaters and reheaters from fouling due to ash deposition. In the case of oil and gas fired boilers this loading will be high, however taking care of the metal temperatures in the water wall and maintaining an optimum gas temperature for the heat transfer in superheater/reheater. The plan area heat loading can be correlated to the maximum localized heat absorption rate and maximum temperature of products of combustion. In other words, a very high plan area loading may tend the furnace to slag in the case of coal fired boilers and increase the furnace wall temperatures in the case of oil and gas fired boilers. The normal value for coal ranges from 3 to 4 x 10^6 K.Cal/hr/m^2 and for oil and gas a maximum value of unto 5 x 10^6 k.Cal/hr/m^2 shall be used.

The volumetric heat loading are important criteria especially for fuels critical about stabilization for combustion and low heating value gases. A low value of volumetric heat loading signifies an increased residence time in the furnace for the combustion to complete. The values used for the normal fuels range from 130 to 300 x 10^3 K.Cal/hr/cu.ft.

Burner clearance

Sufficient height between the top row of fuel nozzles and the furnace outlet must be provided especially in the case of coal fired boilers to obtain complete combustion in the furnace. This value ranges from 15 to 20 metres for large utility boiler. In the case of horizontal firing which is adopted mostly for industrial boilers the clearances between the burners, between the side walls and burner nose portions and burner should all be properly sized to avoid flame impingement on the walls and also flame embracing which is not desirable from the combustion and heat absorption point of view.

Design of Superheater and Reheater

The location of superheater and reheater is almost standard based on the past experience.

While finalizing the arrangement of SH/RH proper care should be given to the following areas:

a. Spacing of tubes
b. Fuel gas velocity
c. Depth of the tube bank for cleanability and weldability for maintenance.

Proper spacing of tubes is provided to prevent ash build-ups in the various sections. This tendency decreases with decreasing gas temperatures. Hence the maximum transverse is given for the platen superheaters, I.e. 450 mm and decreased to 225, 150, 100mm at appropriate stages.

Flue gas velocity is an important criteria in the design of superheaters and reheaters. The heat transfer increases with increasing velocities. For oil and gas fired boilers a maximum velocity of upto 50m/sec. can be considered. However in the case of coal fired boilers the advantage in heat transfer due to high velocity is compromised to the erosive tendency of the fly ash. For our typical Indian coals a velocity of 10-12 m/sec. is considered optimum.

SH/RH Temperature characteristics:

The various types of heat transfer taking place in the SH/RH are convection and radiation. Almost all the boilers will be provided with both convection and radiation superheaters. The ratio of surfaces provided depends on the flatness of the steam temperature characteristic preferred. The radiant superheaters call for a very high grade of material and hence the amount radiant surface to be provided is optimized for different applications. The range of load through which the outlet steam (both superheat and reheat) temperature can be maintained at rated value is called control load.

Steam temperature control:

The nominal control of reheat steam temperature is by tilting the burners. The superheater steam temperature is controlled by spray of feed water. Other temperature control methods that are used according to the need and design are:

a. Flue gas recirculation (used for oil and gas fired boilers)
b. Gas by-pass or diverting dampers
c. Non-contract type desuperheater
d. Triflux type reheater
e. Separate firing, auxiliary burners or twin furnace.

Design of Boiler Bank:

The boiler bank is almost a convection heat transfer section with some amount of non-luminous radiation. The arrangement of tubes is mostly inline with a clear spacing of about 25 to 50 mm depending upon the fuel. The normal gas velocities used for the Indian coals are around 10-12 m/sec. Normally no baffle is provided in the boiler bank tubes. However in case of smaller capacity industrial boilers burning clean fuels baffles may also be used for increased heat transfer rates.

Economizer
This is also a convection heat transfer section located in a relatively cooler gas temperature zone and preheats the water entering the drum. The factors to be considered during the sizing of an economiser are given below:
a. The feed water temperature entering economiser.
b. The feed water temperature leaving economiser.
The inlet temperature should not be less than 105/125°C (depending on % S in fuel from 2.1 to 4.1) from the low temperature corrosion point of view. The outlet temperature should preferably be 35 to 45°C lower than the saturation point. This would avoid the steaming tendency in the economizers. However steaming economisers can be used when use of boiler bank can be avoided.

Airheaters:
There are two basic types of airheaters viz. Tubular and Regenerative. The technological developments provide regenerative type airheater even for industrial boilers of medium capacity. The size of the airheater is decided by the air temperature required for drying in the case of coal fired boilers and an optimum temperature is used for oil and gas fired boilers for the required boiler efficiency.

Design of auxiliary equipments:
The major auxiliary equipments for a boiler are the forced draft and induced draft fans and pulverisers in the case of coal fired boilers.
The number of pulverizes is selected based on the allowable compartment heat loadings and fuel quantity to be fired. Normally the pulverisers are selected such that a stand-by mill will be there for normal operating conditions which can be used in case of increased moisture etc. industrial boilers above 60 T/hr. are also considered for pulverised fuel firing. In the case of industrial boilers a minimum of 2 Nos. of pulverisers are preferred from the combustion stability point of view. In stray cases if only one pulveriser is provided for a boiler, the combustion has to be continuously stabilized with oil or gas burners.

Material Selection for Heat Transfer Surfaces:

Furnace:
The complete water wall system of all natural circulation boilers is provided with only carbon steel or 0.5 Moly carbon steel, since the water / vapour mix temperature in the furnace is not going to be more than 25ºC above the saturation temperature at the operating pressure of the system i.e. much less than 425°C

Superheater and reheater:
The superheater and reheater materials provided will be of various grades. The material selection is done after finding out the mid wall metal temperature as well as the outer surface temperature at a number of points selected by experiments in the SH/RH circuits. These temperatures are calculated considering all the possible heat contributions like
a. Direct radiation from furnace

b. Convection and non-luminous radiation
c. Front and rear cavity radiation

Careful consideration is given to the selection of tube thickness. The use of tubes of small thickness for these applications is avoided considering the erosion problems associated with our Indian coals.

The materials used in the superheater and reheater systems are of ASTM specification. The normal types of materials used and their metal temperature limitations are given below:

ASTM		Max. Temp. °C(Oxidation limit)
SA 210 Gr. A 1	Carbon steel	425
SA 209 T1	½ % Mo steel	480
SA 213 T 11	1 % Cr. ½ % Mo.	550
SA 213 T 22	2¼ % Cr. 1 % Mo.	580
SA 213 TP 304 H	18% Cr. 8% Ni.(stainless steel)	700
SA 213 TP 347 H	18% Cr. 10% Ni	700

Boiler Bank and Economizer:

These two sections are at a relatively lower gas temperature and in the water circuit. Hence the materials used are all carbon steel.

Air heater:

The materials used in the airheaters are of carbon steel at high temperature sections and corrosion resistant corten steel for the cold end sections.

Piping Systems

High Pressure Piping Systems:

The trend of modern practice in the design of high pressure piping systems is to make them simple and direct, in preference to the more complicated and expensive layouts used in the past. In designing steam piping systems, the following factors should be given careful consideration:

(1) The system should be made safe by using the best available material in its construction. The type of joints, fittings, and valves should be carefully selected, bearing in mind the steam pressure and temperature used in the system.
(2) All piping should be relatively simple and direct, and properly supported, also accessible to facilitate maintenance and repairs, and at the same time improve the reliability of plant operation.
(3) The system should insure uninterrupted service, should have proper drainage and should be insulated to prevent heat loss.
(4) Pipe expansion and contraction, due to temperature changes, and the resultant thrusts produced upon supports and anchorages should be determined and provisions made to take care of them.
(5) The pressure drop through a piping system should be relatively small.
(6) The general appearance of the installed system should be pleasing to the eye.

In the layout of a high pressure piping system, the main steam lines, carrying the superheated steam from the boilers to the prime movers, usually take precedence as to location and are considered in more detail before taking up the piping used for the auxiliaries. The design of the main steam lines depends on the pressure and temperature of the transmitted steam and the location and arrangement of the steam generating equipment with respect to the power generating units and auxiliaries supplied with steam.

In many power plants the single header, having its length subdivided into sections by properly located valves, is used. These valves make it possible to divide the station into independent units, thus facilitating testing the equipment and localizing breakdown troubles. In the majority of such installations the header is located on the boiler room side of the wall between the turbine and boiler rooms. In such an arrangement the steam flows directly from the boilers to the prime movers and permits using a somewhat smaller header than that required in either the loop or duplicate steam main systems. The last two systems referred to are only occasionally used at the present time. In high pressure installations it is desirable to minimize the chance of steam leaks, and this may be accomplished by eliminating the number of joints by using a so-called manifold in place of the subdivided single header mentioned above. In the older plants where two or more boilers are required to supply the steam for a single turbo-generating unit, the manifold is somewhat more complicated than that used in a plant of more recent design having a single boiler per turbo-generating unit. The manifolds are interconnected by a tie-over line so that in case of emergency, one generating unit may have more than one source of steam supply. The single-header system has the following advantages over the loop and duplicate main systems:

1. Requires less piping, valves, fittings, and insulation.
2. Requires smaller piping, hence it is cheaper to install.
3. Due to the smaller piping, the radiation losses are less.

The superheated steam used by auxiliaries is frequently distributed through a separate header connected at some convenient point in the main steam line. If saturated steam is used in the plant, it is taken from the boiler drums and is distributed by a header of simple design.

Flexibility of Piping:

In any piping system carrying steam, provisions must be made for the expansion and contraction due to temperature changes. The following methods are used for introducing flexibility into a steam piping system, thereby providing for expansion and contraction: First, by the use of expansion joints; second, by the inherent flexibility of the elements used in building up the piping system; third, by means of double-swing screwed fittings. In any installation, the pressure and temperature prevailing and the expected amount of thermal expansion determine, in a general way, which of the three methods should be used.

Expansion Joints:
Various types of expansion joints are available for taking care of thermal expansion in piping and in general, they may be grouped into two classes, the first of which depends upon packed joints to prevent leakage and the second having no packing. The packed type of joint has been successfully used for steam lines at pressures of 250 pounds per square inch and with moderate degrees of superheat. A number of different designs are available, but due to the packed joint the maintenance cost, caused by leakage, may be relatively high. Joints of this type should be readily accessible for inspection and maintenance. The pack less type includes the diaphragm type, corrugated copper joint and the rubber expansion joint. The diaphragm and the reinforced copper types are occasionally used for moderate pressure lines carrying steam. The plain corrugated copper and rubber joints are primarily used for vacuum service.

Inherent Flexibility of Elements:
The method most frequently used, to take up thermal expansion in high-pressure high-temperature piping systems, is by utilizing the elastic properties of the piping itself. In the majority of installations, this can readily be accomplished by arranging some of the straight runs at right angles to each other through the medium of long radius bends, cast or forged elbows or the modern forged bends used in welded construction. Another means of introducing flexibility, by directional changes, is by the use of expansion bends made entirely of a single piece of pipe, as for example, the U-bend, the double offset U-bend, the single-offset quarter-bend and the circle-bend. The radius of the expansion bends should be free five to six times the diameter of the pipe so that it will not be too stiff. The length of the straight part at each end of the bend should never be less than twice the diameter of the pipe.

Pipe Insulation:
Pipe insulation is used to decrease the losses due to radiation. Experiments made on bare steam pipes show that each square foot of surface will radiate about 3 B.Th.U per hour for each degree Fahrenheit difference between the temperature of the steam and that of the surrounding air. This loss depends upon the size and position of the pipe and the velocity and humidity of the surrounding air. High grade commercial insulation applied properly will save form eighty to ninety percent of the heat radiated from a bare pipe. As a rule, it is well worth while to determine by means of an economic study what thickness of pipe insulation gives the largest return on the investment. Two methods are commonly used for determining safe surface temperature the economic thickness of pipe covering. The first of these methods selects that thickness giving the minimum annual operating expense, and the second selects the thickness on the basis that the best increment of thickness pays a required minimum return of the additional cost. In selecting the type of insulation required for highly superheated steam piping, it should be remembered that magnesia and similar substances deteriorate at temperatures in the neighbourhood of 600 degrees F (315ºC) and are bulky and costly to apply. Hence in modern high temperature piping insulation, the material in contact with the pipe must be a poor heat

conductor capable of withstanding high temperatures and slag wool mattresses are often used. For low temperature application, covering are not subjected to excessive temperatures, 85 percent magnesia or other high grade insulating material could safely be used for these layers.
Commercial pipe covering may be obtained in sections molded to the proper form, thus facilitating their application and removal. These sections are held in place by metal bands. In any pipe line the flanges as well as valves and fittings should be suitably covered.

SAMPLE QUESTIONS

Q.1 What load characteristics are necessary in the design of a steam generator?

Q.2 Differentiate between Water tube boiler and fire tube boiler

Q.3 Size of boiler tubes is specified by:
a) inside diameter and thickness
b) outside diameter and thickness
c) outside diameter and inside diameter
d) none of the above

Q.4 Answer the questions as stated below:
a) How does the boiling of water in a tube effect heat transfer?
b) Why are bent tubes used in a water tube boiler?

Q.5 Write short notes with necessary sketches.
Types of expansion joints and their function