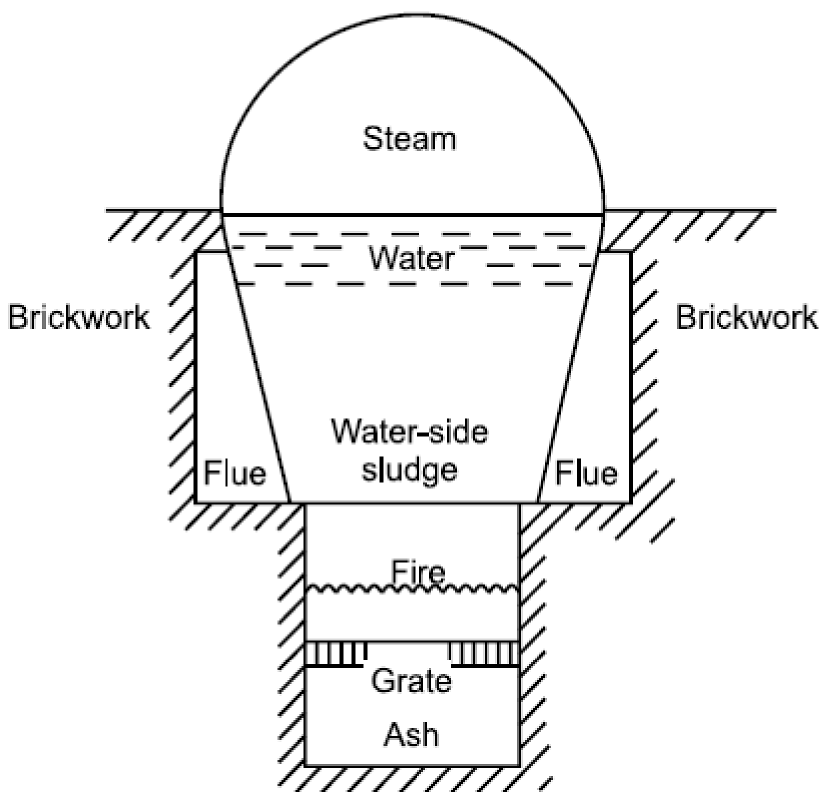
<u>**Unit -1**</u>

<u>**Steam Generators**</u>

INTRODUCTION

Steam is extensively used for various applications such as power production, industrial processes, work interaction, heating etc. With the increasing use of steam in different engineering systems the steam generation technology has also undergone various developments starting from 100 B.C. when Hero of Alexandria invented a combined reaction turbine and boiler. Boiler, also called steam generator is the engineering device which generates steam at constant pressure. It is a closed vessel, generally made of steel in which vaporization of water takes place. Heat required for vaporization may be provided by the combustion of fuel in furnace, electricity, nuclear reactor, hot exhaust gases, solar radiations etc. Earlier boilers were closed vessels made from sheets of wrought iron which were lapped, riveted and formed into shapes of simple sphere type or complex sections such as the one shown in Fig. It is the ‘Wagon boiler’ of Watt developed in 1788.



***Wagon boiler of Watt*, (1788)**

According to A.S.M.E. (American Society of Mechanical Engineers, U.S.A.) code a boiler is defined as a combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to water which could be heated and vaporized to steam form.

TYPES OF BOILERS

Boilers are of many types. Depending upon their features they can be classified as given under:

(a) Based upon the orientation/axis of the shell: According to the axis of shell boiler can be classified as vertical boiler and horizontal boiler.

(i) *Vertical boiler* has its shell vertical.

(ii) *Horizontal boiler* has its shell horizontal.

(iii) *Inclined boiler* has its shell inclined.

(b) Based upon utility of boiler: Boilers can be classified as

(i) *Stationery boiler*, such boilers are stationery and are extensively used in power plants, industrial processes, heating etc.

(ii) *Portable boiler*, such boilers are portable and are of small size. These can be of the following types,

Locomotive boiler, Marine boiler.

(c) Based on type of firing employed: According to the nature of heat addition process boilers can be classified as,

(i) Externally fired boilers, in which heat addition is done externally i.e. furnace is outside the boiler unit, such as Lanchashire boiler, Locomotive boiler etc.

(ii) Internally fired boilers, in which heat addition is done internally i.e. furnace is within the boiler unit, such as Cochran boiler, Bobcock Wilcox boiler etc.

(d) Based upon the tube content: Based on the fluid inside the tubes, boilers can be,

(i) *Fire tube boilers*, such boilers have the hot gases inside the tube and water is outside surrounding them. Examples for these boilers are, Cornish boiler, Cochran boiler, Lancashire boiler, Locomotive boiler etc.

(ii) *Water tube boilers*, such boilers have water flowing inside the tubes and hot gases surround them. Examples for such boilers are Babcock-Wilcox boiler, Stirling boiler, La-Mont boiler, Benson boiler etc.

(e) Based on type of fuel used: According to the type of fuel used the boilers can be,

(i) *Solid fuel fired boilers*, such as coal fired boilers etc.

(ii) *Liquid fuel fired boilers*, such as oil fired boilers etc.

(iii) *Gas fired boilers*, such as natural gas fired boilers etc.

(f) Based on circulation: According to the flow of water and steam within the boiler circuit the boilers may be of following types,

(i) *Natural circulation boilers*, in which the circulation of water/steam is caused by the density difference which is due to the temperature variation.

(ii) *Forced circulation boilers*, in which the circulation of water/steam is caused by a pump i.e. externally, assisted circulation

(g) Based on extent of firing: According to the extent of firing the boilers may be,

(i) *Fired boilers*, in which heat is provided by fuel firing.

(ii) *Unfired boilers*, in which heat is provided by some other source except fuel firing such as hot flue gases etc.

(iii) *Supplementary fired boilers*, in which a portion of heat is provided by fuel firing and remaining by some other source.

REQUIREMENTS OF A GOOD BOILER

Different requirements of a good boiler are given below. In general boiler is supposed to generate large quantity of steam at desired pressure and temperature quickly and efficiently.

(a) It should be capable of generating steam at desired rate at desired pressure and temperature with minimum fuel consumption and cost.

(b) It should have sufficient steam and water storage capacity to meet fluctuation in demand and to prevent fluctuation in steam pressure or water level.

(c) Boiler should have a constant and thorough circulation of water.

(d) It should be equipped with all necessary mountings.

(e) Boiler should have capability to get started quickly from cold.

(f) Its construction should be simple and have good workmanship for the ease of inspection and repairs i.e. easily accessible parts.

(g) Boiler should have its heating surface nearly at right angle to the current of hot gases for good heat transfer.

(h) There should be minimum frictional power loss during flow of hot gases and water/steam i.e. pressure drop throughout the system should be minimum.

(i) Tubes should be so designed so as to have minimum soot deposition and good strength against wear. Boiler should have a mud drum to receive all impurities.

(j) Boiler should have strength to withstand excessive thermal stresses.

(k) Boiler should occupy less floor area and space.

Boilers may be selected for a particular applications considering above general requirements and constraints, if any. For deciding the boiler for any application, generally following criterion are made;

(i) Steam pressure requirement

(ii) Steam temperature requirement

(iii) Steam generation rate

(iv) Initial cost and constraints

(v) Running and maintenance costs

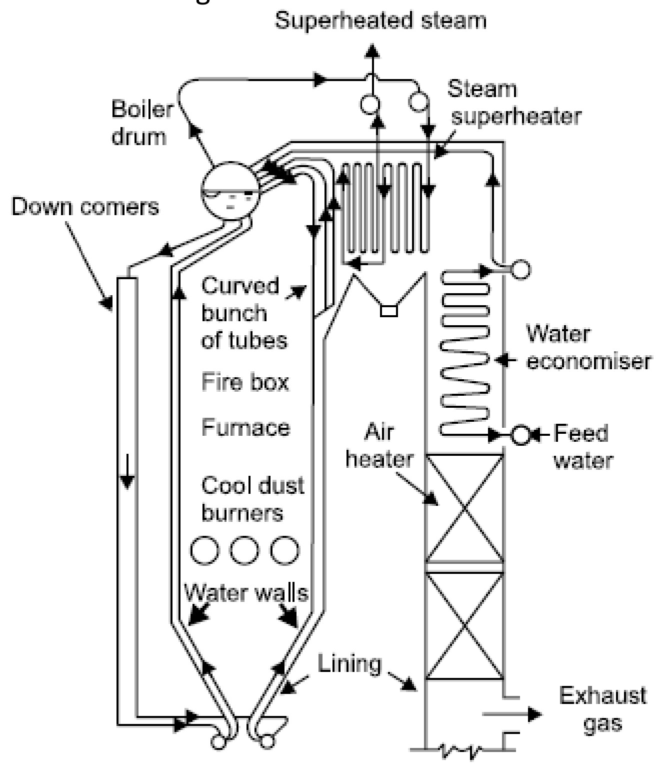
(vi) Availability of fuel and water

(vii) Inspection and maintenance requirements

HIGH PRESSURE BOILER

High pressure boilers generally operate in supercritical range. Need of such boilers is felt because high pressure and temperature of steam generated in boiler improves plant efficiency. These boilers have forced circulation of water/steam in the boiler. This forced circulation is maintained by employing suitable pump. The steam drum is of very small size and in some cases it may be even absent too. This

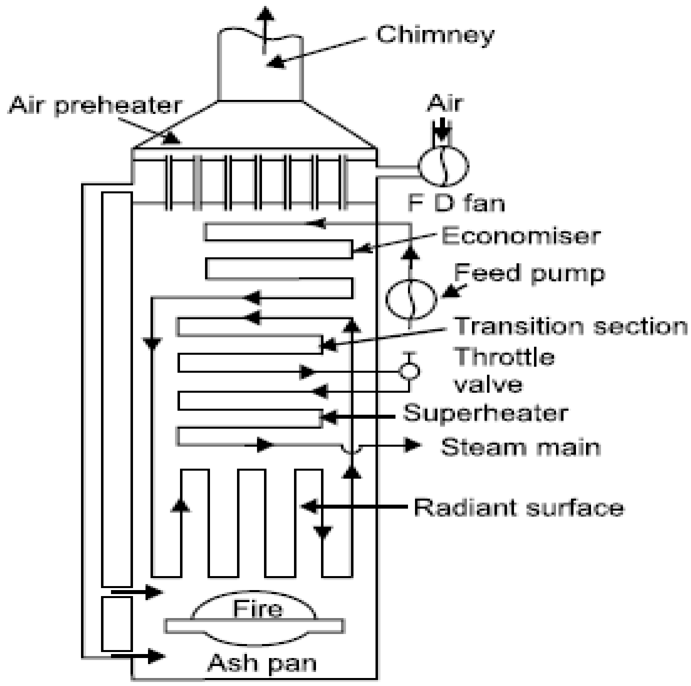
is because of using forced circulation. In case of natural circulation drum size has to be large. Schematic of high pressure boiler is shown in figure. In fact the high pressure boilers have been possible because of availability of high temperature resistant materials. Here direct heating of water tubes is done by the excessively hot gases present in fire box. The fire box has large volume as otherwise exposed water tubes shall melt. Heat is picked by number of parallel tubes containing water. These parallel tubes appear as if it is a wall due to close spacing of tubes. Water circulation circuit is shown in line diagram. High pressure boilers may have natural circulation in case the steam pressure desired lies between 100 and 170 bar and size is not constraint. High pressure boilers have capability of generating larger quantity of steam per unit of furnace volume. High pressure boilers are disadvantageous from safety point of view and therefore, stringent reliability requirements of mountings are there.



High pressure boiler with natural circulation

BENSON BOILER

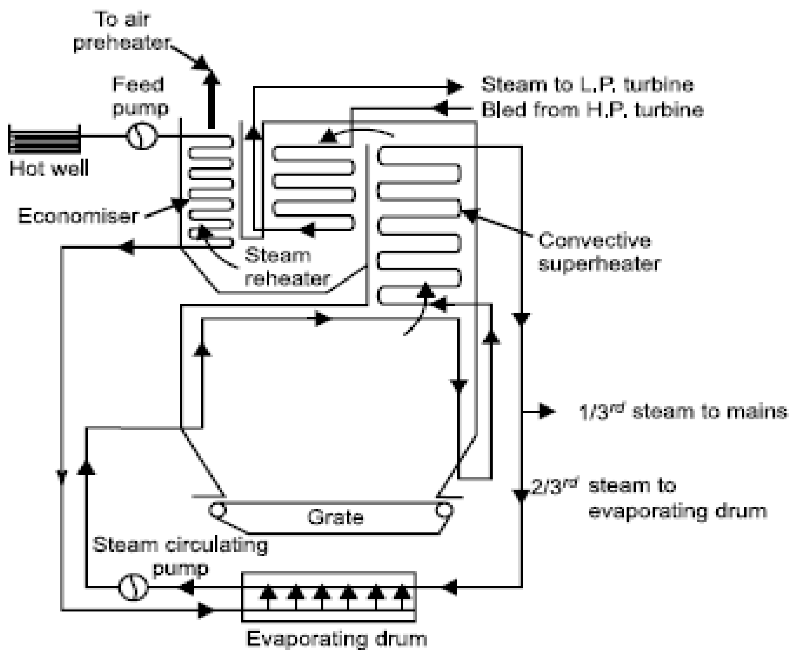
It is a water tube boiler capable of generating steam at supercritical pressure. Figure. show the schematic of Benson boiler. Mark benson, 1992 conceived the idea of generating steam at supercritical pressure in which water flashes into vapour without any latent heat requirement. Above critical point the water transforms into steam in the absence of boiling and without any change in volume i.e. same density. Contrary to the bubble formation on tube surface impairing heat transfer in the normal pressure boilers, the supercritical steam generation does not have bubble formation and pulsations etc. due to it. Steam generation also occurs very quickly in these boilers. As the pressure and temperatures have to be more than critical point, so material of construction should be strong enough to withstand thermal stresses. Feed pump has to be of large capacity as pressure inside is quite high, which also lowers the plant efficiency due to large negative work requirement. Benson boilers generally have steam generation pressure more than critical pressure and steaming rate of about 130–135 tons/hr. Thermal efficiency of these boilers is of the order of 90%.



Benson boiler

LOEFFLER BOILER

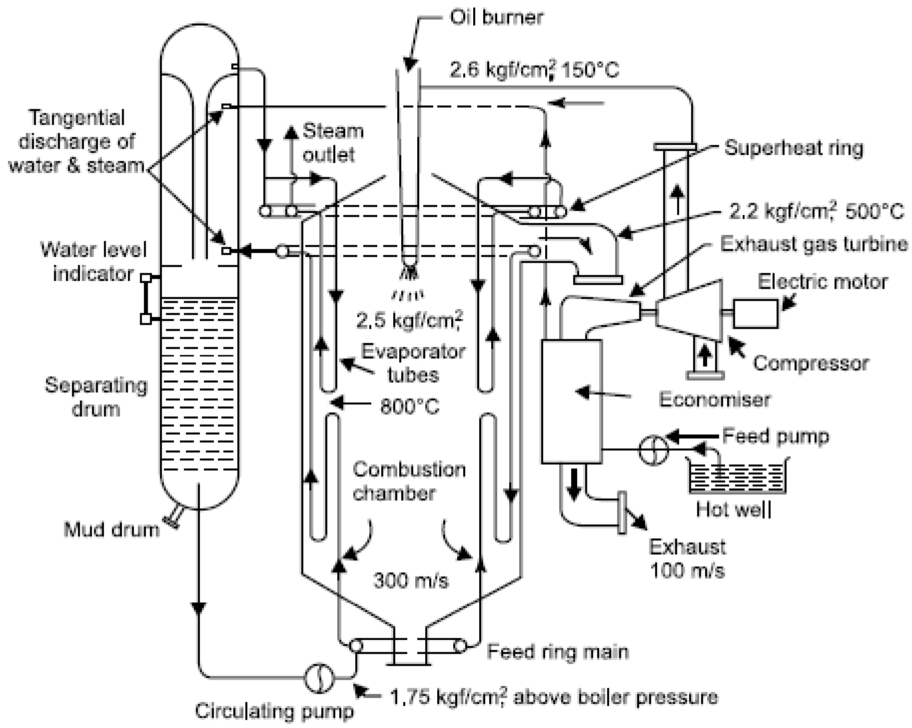
This a forced circulation type boiler having both direct and indirect type of heat exchange between superheated steam/water and hot gases/steam respectively. Schematic arrangement of a Loeffler boiler is shown in Fig. Here the hot combustion gases emerging out of furnace are firstly used for superheating of steam and secondly for reheating/economiser sections. Steam generation is realized through the superheated steam being injected into evaporator drum. Saturated steam thus generated in evaporator drum as a result of mixing of superheated steam and water is picked up by steam circulation pump. This pump forces saturated steam at high pressure through superheater tubes where the hottest flue gases from furnace superheat steam coming from evaporator. Flue gases subsequently pass through reheated/economizer sections as shown. Superheated steam coming out of superheater section is partly taken out through steam main and remaining is injected into evaporator drum. Generally superheated steam is divided in proportion of 1: 2 for steam main and evaporator drum respectively. Feed water to the boiler is pumped by feed pump through the economiser section to evaporator drum. Generally steam generated is at pressure of about 120 bar and temperature of 500 C.



Schematic arrangement in Loeffler Boiler

VELOX BOILER

Velox boiler is a fire tube boiler having forced circulation. Boiler has gas turbine, compressor, generator, feed pump, circulation pump etc. as its integral components. Thus Velox boiler unit is a compact steam generating plant. Figure shows the line diagram of Velox boiler unit. Boiler unit has a compressor supplying high pressure air at about 3 bar into the oil burner so as to produce combustion products at high pressure and thus have hot flue gases flowing through fire tubes at very high velocity of the order of supersonic velocity. Flue gases flowing at supersonic velocity

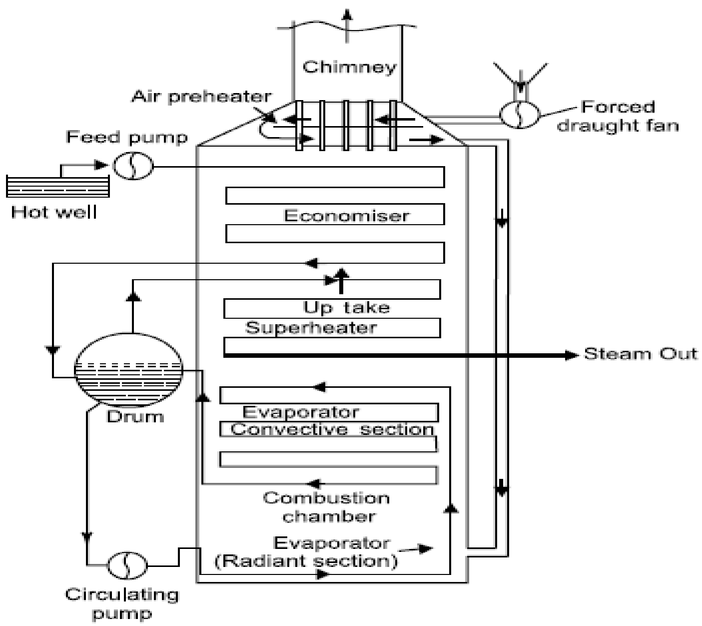


Velox boiler unit

Facilitate very high rate of heat interaction between two fluids, generally of the order of 2 - 107 kcal/m3 of combustion volume. Combustion space is lined with concentric vertical tubes having hot flue gases passing through the inner tube and water surrounding it in outer tube. Hot flue gases pass through superheater section and subsequently enter into gas turbine for its expansion. Gas turbine drives the compressor used for producing compressed air. Expanded gases coming out of gas turbine at about 100–125 m/sec enter into economiser where feed water picks up heat from gas turbine exhaust. Hot feed water coming out of economiser is sent into steam/water drum from where water is circulated through vertical concentric tubes using a circulating pump. During the water flow in combustion volume space it partially gets transformed into steam and the mixture is injected tangentially into drum. Tangential discharge of mixture forms a circulatory flow (vortex) causing steam release due to centrifugal action, thus separation of water/steam. Steam is subsequently passed through superheater section while water is again circulated using circulation pump. Steam passes through steam headers after superheating. Surplus energy, if any in gas turbine is used by alternator attached to it which supplements the electricity requirement in various auxiliary devices. Velox boilers are very flexible and capable of quick starting. Overall efficiency of the boiler unit is about 55–60%. Boiler is capable of handling maximum of 100 tons/hr water which is limited by the limitation of maximum power requirement in compressor

LA MONT BOILER

This is a water tube boiler having forced circulation. Schematic showing the arrangement inside boiler is given in Fig. Boiler has vertical shell having three distinct zones having water tubes in them, namely evaporator section, superheater section and economiser section Feed water is fed from feed pump to pass through economiser tubes. Hot water from economizer goes into drum from where hot feed water is picked up by a circulating pump. Centrifugal pump may be steam driven or of electric driven type. Pump increases pressure and water circulates through evaporation section so as to get converted into steam and enters back to drum. Steam available in drum enters into superheater tubes and after getting superheated steam leaves through steam main.



BOILER MOUNTINGS AND ACCESSORIES

Boiler mountings and accessories have been defined earlier and shown on the different boilers. Different mountings are

(i) Water level indicator
(ii) Safety valves
(iii) High steam and low water safety valves
(iv) Fusible plug
(v) Pressure gauge
(vi) Stop valve
(vii) Feed check valve
(viii) Blow off cock
(ix) Manhole and mud box

Various boiler accessories are:

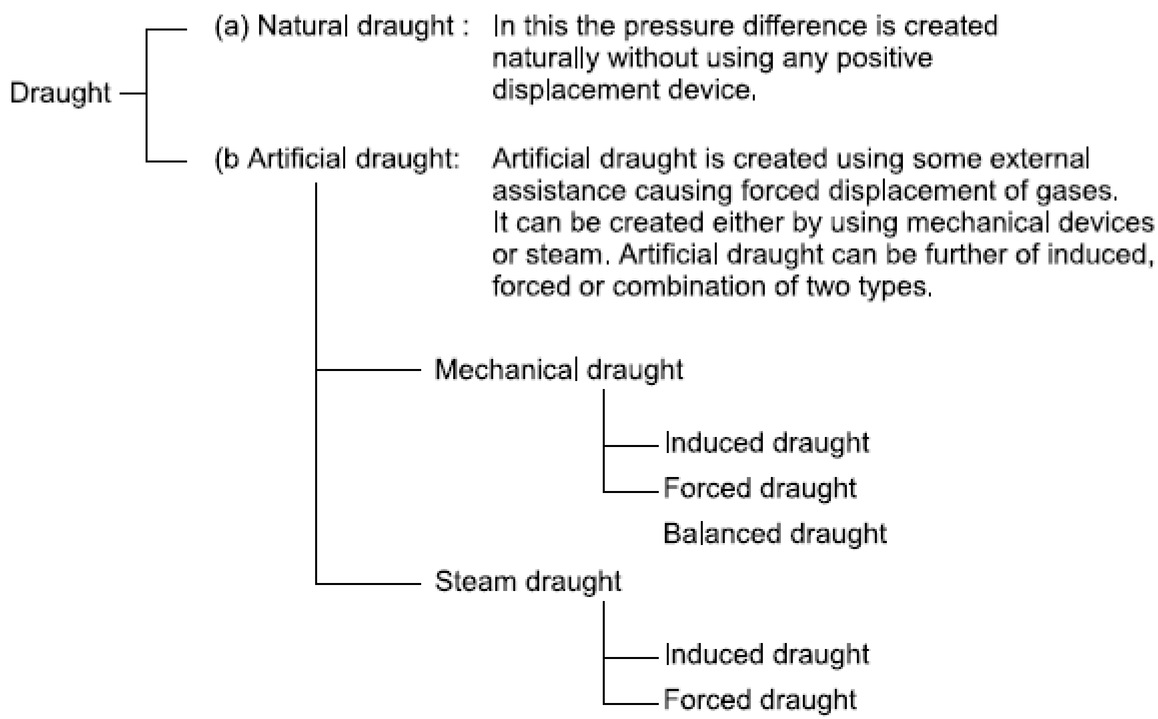
(i) Superheater
(ii) Economiser
(iii) Air preheater
(iv) Feed pump

BOILER DRAUGHT

Draught refers to the pressure difference created for the flow of gases inside the boiler. Boiler unit has a requirement of the expulsion of combustion products and supply of fresh air inside furnace for continuous combustion. The obnoxious gases formed during combustion should be discharged at such an height as will render the gases unobjectionable. A chimney or stack is generally used for carrying these combustion products from inside of boiler to outside, i.e. draught is created by use of chimney. Draught may be created naturally or artificially by using some external device. Draught can be classified as below:

- In this the pressure difference is created naturally without using any positive displacement device.
- Artificial draught is created using some external assistance causing forced displacement of gases. It can be created either by using mechanical devices or steam. Artificial draught can be of induced type, forced type or combination of two types.

Thus the draught in boiler may be said to be required for, providing and maintaining the supply of sufficient air for combustion expulsion of combustion products from furnace region' and 'discharge of burnt gases to atmosphere. The amount of draught required shall depend upon, 'type of boiler', 'rate of fuel burning rate at which combustion products are produced' and 'the air requirement rate. As the pressure difference is very small so draught is measured in 'mm' of water. Mathematically, pressure due to 1 mm of water column is equivalent to 1 kgf/m2.



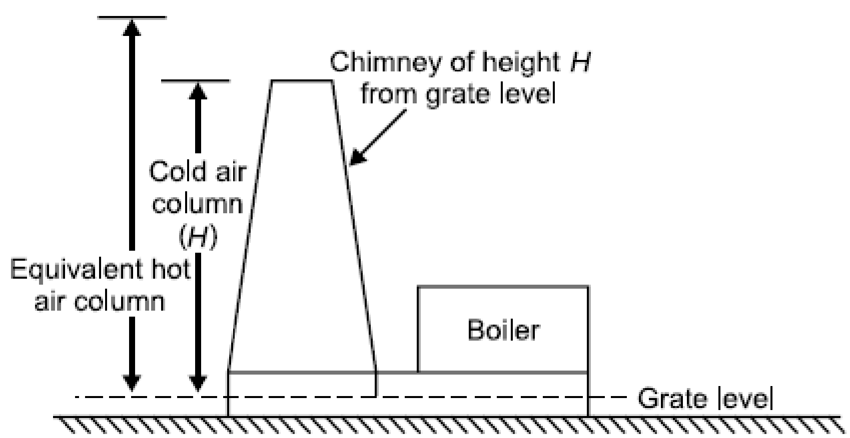
NATURAL DRAUGHT

It is produced employing chimney. The natural draught is produced by a chimney due to the fact that the hot gases inside the chimney are lighter than the outside cold air i.e. density difference of hot gases inside chimney and cold atmospheric air. Thus in a boiler unit the combustion products (hot) rise from fuel bed through chimney, and are replaced by fresh air (cold) entering the grate. It means that amount of draught produced by a chimney depends upon flue-gas temperature. Intensity of draught produced by chimney also depends upon height of chimney.

Draught produced by a taller chimney is large as the difference in weight between the column of air inside and that of air outside increases with height. Generally draught is less than 12 kgf/m^2 in chimneys.

In stricter terms the word ‘chimney’ is used for brick or concrete structure and ‘stack’ is used for metallic one. Chimneys are generally made of steel, brick or reinforced concrete. Steel chimneys or stacks are most desirable for smaller boiler units due to small initial cost, ease of construction and erection. On account of small space requirement as compared to other stacks, self sustaining steel stacks are used in some large power plants. Steel stacks have problem of rust and corrosion, so painting requirements are quite stringent. Brick chimneys are required where permanent chimney with longer life is required. Such chimneys have inherent disadvantages of leakages etc. across the construction, therefore careful construction is required. Leakage of air across chimney wall effects intensity of draught. Brick chimneys are constructed of round, octagonal, or square section. Generally brick chimney has two walls with air space between them and inner wall having fire brick lining. Concrete chimneys are used due to the absence of joints, light weight and space economy as compared with brick chimneys. Also the reinforced concrete chimney is less expensive compared to brick chimney along with minimum chances of leakage across walls.

Calculations: As it is obvious from earlier discussion that the vertical duct called chimney creates natural draught so estimation of height of chimney is very important. Figure shows the schematic of chimney in a boiler unit. During no working of boiler the pressure inside boiler is atmospheric pressure. Pressure at outlet of chimney will be less than atmospheric pressure due to altitude difference.



EQUIVALENT EVAPORATION

From earlier discussions it is seen that there exists a large variety of the boilers in terms of their arrangement, efficiency, steam generation rate, steam condition, type of fuel used, firing method and draught etc. For comparing one boiler with other any of the above parameters cannot be considered as they are interdependent. Therefore, for comparing the capacity of boilers working at different pressures, temperatures and different final steam conditions etc. a parameter called “equivalent evaporation” can be used. Equivalent evaporation actually indicates the amount of heat added in the boiler for steam generation. Equivalent evaporation refers to the quantity of dry saturated steam generated per unit time from feed water at 100_C to steam at 100_C at the saturation pressure corresponding to 100_C. Sometimes it is also called equivalent evaporation from and at 100_C. Thus, mathematically it could be given as

$$\text{Equivalent evaporation} = \frac{\text{Mass of steam generated per hour} \times (\text{Heat supplied to generate steam in boiler})}{\text{Heat supplied for steam generation at } 100°\text{C from water at } 100°\text{C (i.e. Latent heat)}}$$

Boiler Efficiency:

HEAT BALANCE ON BOILER

Heat balance on boiler refers to the accounting for total heat released inside boiler and its distribution. Total heat available inside boiler is due to burning of fuel and can be quantified by the product of mass of fuel and heating value of fuel. Heat distribution can be given comprising of the following, based on unit mass of fuel burnt.

Numerical problem:-

1. Determine the height of chimney required to produce draught equivalent to 16.7 mm of water column for the flue gases at 300_C and ambient temperature of 20_C. Take the air requirement to be 20 kg/kg of fuel.(30m)
2. Calculate the draught produced in *mm* of water by chimney of 35 m height, flue gas temperature of 643 K, boiler house temperature of 307 K and air supplied at 18.8 kg per kg of coal (20mm).

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