Mechanical Engineering

FUNDAMENTALS

Devendra Vashist

Mechanical Engineering: Fundamentals

Devendra Vashist
Associate Professor
Manav Rachna International University
Faridabad, Haryana

I.K. International Publishing House Pvt. Ltd.
NEW DELHI • BANGALORE

Contents

UNIT 3

Properties of Steam and Steam Generators (Boilers)

After going through this unit, the reader is required to understand the following:

(1) How to use steam tables.
(2) How to make calculations with Mollier chart.
(3) Methods for finding out the dryness fraction of steam.
(4) Cochran and Babcock and Wilcox boiler.
(5) Boiler mountings.
(6) Boiler accessories.

3.1 PROPERTIES OF STEAM AND BOILERS

Steam is a vapour. It is used for heating and as the working substance in the steam engine and steam turbine plants. Properties of steam were first investigated by Regnault and subsequently by Prof. Callendar. Properties of steam are given in the form of tables and also in form of charts. The datum used for the calculation of properties of steam is 0ºC. All values measured above this temperature are considered positive and those measured below are taken as negative. Steam is a pure substance and like any other pure substance, it can be converted into any of the three states i.e. solid, liquid and gas. A system composed of liquid and vapour phases of water is also a pure substance. Even if some liquid is vaporized or some vapour gets condensed during a process, the system will be chemically homogenous and unchanged in chemical composition.

Formation of Steam at Constant Pressure

Assume that a unit mass of steam is generated starting from solid ice at –20ºC at 1 atm pressure in a cylinder and piston machine. The distinct regimes of heating are:

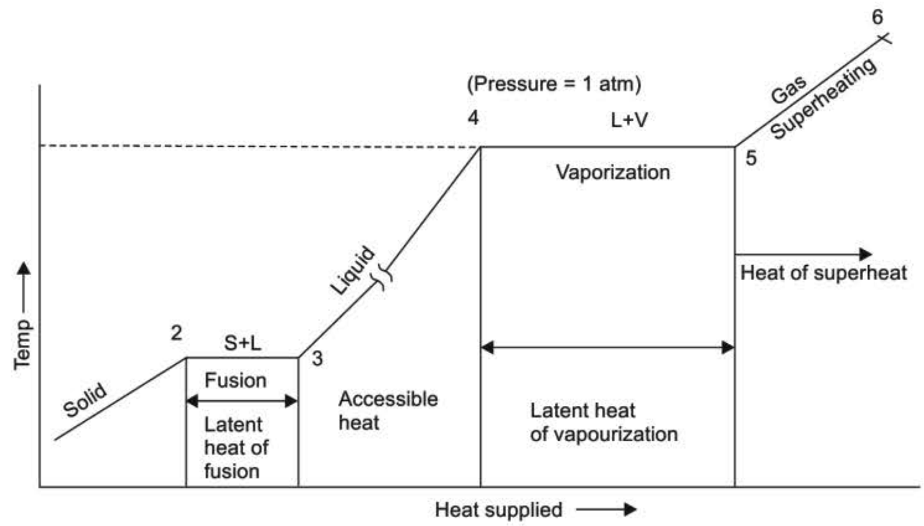


Fig. 3.1

Regime (1–2): The heat given to ice increases its temperature from –20ºC to 0ºC. The volume of ice increases with the increase in temperature. Point 2 shows the saturated solid condition. At 2, the ice starts to melt.

Regime (2–3): The ice melts into water at constant pressure and temperature. The amount of heat supplied per kg of the substance is called latent heat of fusion. At 3, the melting process ends. There is a sudden decrease in volume at 0ºC as the ice starts to melt. It is a peculiar property of water due to breaking of hydrogen bonding.

Regime (3–4): The temperature of water increases on heating from 0ºC to 100ºC as shown in figure. The volume of water first decreases with the increase in temperature, reaches to its minimum at 4ºC and again starts to increase because of thermal expansion. Point 4 shows the saturated liquid condition.

Regime (4–5): The water starts boiling at 5. The liquid starts to get converted into vapour. The boiling ends at point 5. Point 5 shows the saturated vapour condition at 100ºC and 1 bar. The amount of heat supplied during the process is called latent heat of vaporization.

Regime (5–6): It shows the superheating of steam above saturated steam point. The volume of vapour increases rapidly and it behaves as a perfect gas. The difference between the superheated temperature and the saturation temperature at a given pressure is called degree of superheat.

Points 2,3,4,5 are known as saturation states. State 2 is saturated solid state while states 3 and 4 are saturated liquid state. State 3 is for fusion and state 4 is for vaporization. State 5 is saturated vapour state. At saturated state, the phase may get changed without change in pressure or temperature.

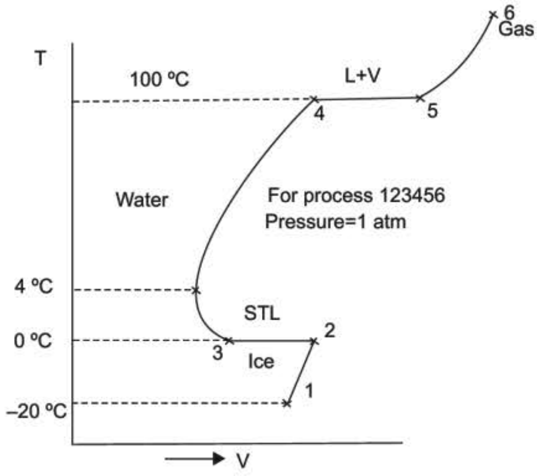


Fig. 3.2

Effect of Pressure on Saturation Temperature

The boiling temperature of water increases with the increase of pressure. The boiling temperature of water at a particular pressure is called saturation temperature and corresponding pressure is known as saturation pressure. The saturation temperature at every pressure is uniquely fixed. The variation of saturation temperature with saturation pressure is shown in the figure.

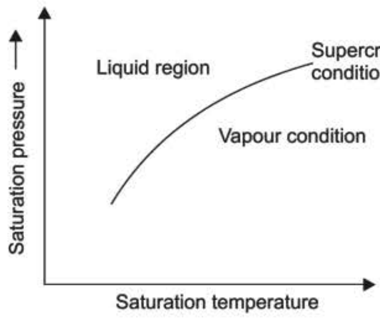


Fig. 3.3

Critical temperature: The critical temperature of water is defined as the temperature at which water evaporates into steam without taking any latent heat. Above this temperature, it is impossible to liquefy the steam. The saturation pressure corresponding to critical temperature is called critical pressure. The critical temperature and critical pressure of water are 374.15°C and 221.20 bar respectively. Above critical point, all differences in the properties of liquid and vapour disappear.

Triple point: At very low pressure, melting point and boiling point coincide together and all the three states–solid, liquid and gas remain in equilibrium. This temperature is called triple point. For water at .006114 bar, the triple point is 273.16°K.

Generation of Steam

The amount of heat required to raise the temperature of ice to the melting

point $= h_i = C_{pi} (t_i - t_0)$

where t_0 = initial temperature of ice
t_i = melting point of ice
C_{pi} = specific heat of solid state

Total heat required for melting of ice $= C_{pi} (t_i - t_0) + h_{if}$ where h_{if} = enthalpy of melting = latent heat of fusion. Addition of heat to water from latent point to saturated liquid at saturation temperature is called sensible enthalpy. $= h_f = 1 \times C_{pw} (t_s - t_i)$ where C_{pw} = specific heat of water, t_s = saturation temperature.

Latent heat of evaporation $= h_{fg}$.

On further heating superheated steam is generated. Total heat added from initial temperature to final temperature of superheated steam (t_{sup}) can be given by:

$$h_{sup} = C_{pi} (t_i - t_0) + h_{if} + h_f + h_{fg} + C_{ps} (t_{sup} - t_s)$$

where C_{ps} = specific heat of superheated steam
t_s = saturation temperaure

Average value of Cps = 2.0934 KJ/Kgk

$(t_{sup} - t_s)$ is called degree of superheat

Again take an example:

Let us consider 1 kg of water at 0°C (datum temperature of enthalpy) contained in a cylinder filled with a frictionless piston exerting a constant pressure (P) in the cylinder all the time. As heat is supplied the temperature of water continues to increase until saturation temperature is attained. The heat supplied in this process is given by $h_f = C_{pw} (t_s - 0)$.

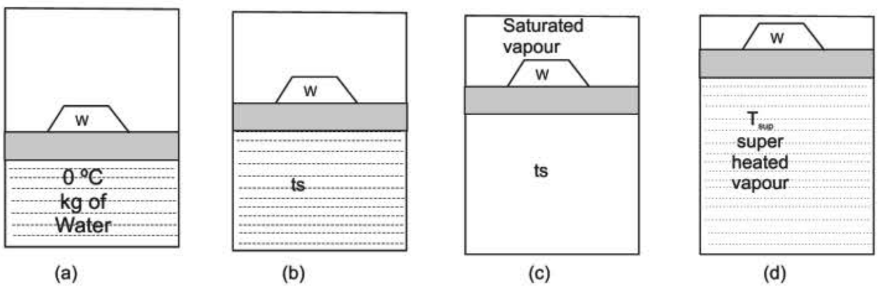


Fig. 3.4

where C_{pw} = specific heat of water at constant pressure. This heat is called enthalpy of saturated liquid. Further addition of heat is used to change the phase from liquid to vapour. This is continued until the entire liquid is converted into vapour. Now the total heat required to convert entire 1 kg of water at 0ºC into steam at t_sºC is given by:

$$h_g = h_f + h_{fg}$$

h_{fg} is called latent enthalpy or enthalpy of evaporation and h_g is called enthalpy of saturated vapour. Further addition of heat will increase the temperature of steam above the saturation temperature. One such condition has been shown in figure. The quantity of heat during superheating is given by $C_{ps}(t_{sup} - t_s)$ and total heat of superheated steam

$$= h_{\text{sup}} = h_g + C_{ps}(t_{\text{sup}} - t_s)$$

Quality of Steam

The steam may exist in three conditions, namely:

(1) Wet
(2) Dry saturated
(3) Superheated

Wet steam: Steam generated in the presence of water with which it is in the state of equilibrium is known as wet steam. The water present in the wet steam is saturated liquid at saturation temperature.

Dry saturated steam: The steam which does not contain any liquid particle but is at saturated temperature is called dry saturated steam.

Superheated steam: If the temperature of the dry steam is increased more than the saturation temperature steam becomes superheated.

The steam ordinarily produced in any boiling vessel is always wet steam as it contains liquid particles in a finely divided liquid droplet, etc. Entire liquid has not taken latent heat. The state of wet steam will be somewhere in between saturated liquid state (2) and dry vapour state (3).

Let us say state 5. The relative amounts of vapour phase and saturated liquid phase determines the quality of steam. The quality or "dryness fraction" of steam

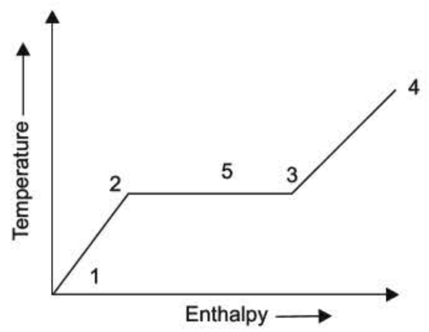


Fig. 3.5

is defined as the ratio of the mass of dry vapour to the total mass of mixture. Thus, dryness fraction

$$x = \frac{\text{Mass of dry vapour in the mixture}}{\text{Mass of the mixture}}$$

For example, if 1 kg of steam contains 0.95 kg of dry vapour, then dryness fraction of steam is 0.95. $(1 - x)$ represents wetness of the steam. The heat required to produce 1 kg of wet steam is given by:

$$h = h_f + xh_{fg}.$$

State 4 represents the condition of superheated steam.

Following advantages occur by using superheated steam in steam power plants:

(i) Increased work capacity without having to increase its pressure.

(ii) Greater heat content of the superheated steam leads to less steam consumption for a given output and that results in saving the cost of the fuel.

(iii) Moisture content of steam leaving the steam turbine/engine can be kept within safe limits. Accordingly, the heat losses due to condensation of steam are avoided to a large extent.

(iv) Superheating is done by utilizing the heat of waste furnace gases which otherwise passes uselessly to the atmosphere.

Thermodynamic Properties of Steam

In the study of various engineering processes and vapour power cycles , thermodynamic properties of steam like specific volume, enthalpy, entropy, internal energy and saturation temperature must be known. The values of these properties are determined either experimentally or otherwise. These properties are available in the form of table and chart. The properties of saturated liquid, saturated vapour and superheated vapour are available. The properties of wet steam are calculated by knowing dryness fraction and pressure of the steam.

The calculation of various properties are given below:

(1) Specific volume

v_f = specific volume of saturated liquid

v_{fg} = specific volume of evaporation

v_g = specific volume of dry steam = $v_f + v_{fg}$

Specific volume of wet steam is given by :

$$v = v_f + xv_{fg} = v_f + x(v_g - v_f) = (1 - x)v_f + xv_g$$

but the specific volume of saturated liquid is very small compared to specific volume of saturated vapour.

Therefore, $v = xv_g$

Specific volume of superheated steam is determined, approximated by the relation

$$v_{sup} = v_g \cdot T_{sup}/T_s$$

because superheated steam behaves as a perfect gas approximately.

(2) Internal energy of steam

Internal energy of steam is the difference of enthalpy and flow work. Therefore, internal energy of saturated liquid is given by:

$$v_f = h_f - P.v_f$$

Internal energy of wet steam

$$v = (h_f + x_{hfg}) - P_{xvg}$$

Internal energy of dry saturated steam

$$= v_g = h_g - P_{vg}$$

Internal energy of superheated steam

$$= v_{sup} = h_{sup} - Pv_{sup} = h_g + C_p\,(t_{sup} - t_s) - Pv_{sup}$$

(3) Entropy of steam

From definition change of entropy $d_s = dQ/T$

Entropy of saturated liquid

$$d = \int_{273+0}^{273+t_s} C_{pw}\frac{dT}{T} = C_{pw}\ \ln\ \frac{273+t_s}{273}$$

$$S_f = C_{pw}\ \ln\ \frac{T_s}{273}$$

0°C (273°K) has been taken as datum.

Latent entropy or entropy of evaporation is $S_{fg} = h_{fg}/T_s$ because during evaporation T_s remains constant.

Entropy of wet steam $= S = S_f + xS_{fg}$

Entropy of superheated steam $= S_{sup} = S_g + \int_{T_s}^{T_{sup}} C_{ps}\ \ln\ dT$

$$= S_{sup} = Sg + Cps\ \ln\ \frac{T_{sup}}{T_s}$$

3.2 STEAM TABLES

The generation of steam at different pressures has been studied experimentally and various properties of steam have been obtained at different conditions. The properties have been listed in tables called steam tables. The steam tables are available for:

1. Saturated water and steam—on pressure basis.
2. Saturated water and steam—on temperature basis.
3. Superheated steam—on pressure and temperature basis for enthalpy, entropy and specific volume.
4. Supercritical steam—on pressure and temperature basis above 221.2 bar and 374.15°C for enthalpy, entropy and specific volume.

Some important points regarding steam tables.

(1) The steam table gives values for 1 kg of water and 1 kg of steam.

(2) The steam table gives values of properties from the triple point of water to the critical point of steam.

(3) For getting values of thermodynamic properties, either saturation pressure or saturation temperature need to be known. Pressure based steam table (i.e. extreme left pressure column is placed) is used when pressure value is known, similarly temperature based steam table is used when temperature value is known.

(4) At low pressure, the volume of saturated liquid is very small as compared to the volume of dry steam and usually the specific volume of liquid is neglected. But at very high pressure the volume of liquid is comparable and should not be neglected.

(5) The specific enthalpy and specific entropy at 0°C are both taken as zero and measurements are made from 0°C onwards.

(6) In computing, the properties of wet steam, it should be noted that only h_{fg} and S_{fg} are affected by dryness fraction but h_f and S_f are not affected by dryness fraction. This means that for steam with dryness fraction x

$$h_{fg} = h_f + xh_{fg}$$

$$S_{fg} = S_f + xS_{fg}$$

(7) The values of properties for superheated steam can be taken from the table for superheated steam or can be calculated by application of ideal gas equation.

Property Table

Property	Wet steam	Dry steam	Superheated steam
Volume	$(1 - x)\, v_f + xv_g$	v_g	$v_g T_{sup}/T_s$
Enthalpy	$h_f + xh_{fg}$	$h_f + h_{fg} = h_g$	$h_g + C_{ps}(t_{sup} - t_s)$
Entropy	$S_f + xS_{fg}$	$S_f + S_{fg} = S_g$	$S_g + C_{ps}\,\text{In}\,(T_{sup}/T_s)$

STEAM PROPERTY CHARTS

In addition to steam table, properties can be represented graphically on a chart. The most convenient charts are the temperature entropy (T–S) and enthalpy-entropy (h–s) charts which were first prepared by Mollier. These charts are discussed below:

(a) Temperature-Entropy Chart (T-S Diagram)

From the diagram, we find the gap between the saturated liquid line and saturated vapour line goes on decreasing with increase of pressure and finally both the lines meet at a point called critical point where latent entropy and latent enthalpy becomes zero. Constant pressure line in the two-phase region is also a constant temperature line. But in superheated region, entropy increases with increase of temperature and therefore, constant pressure line is inclined in superheated region.

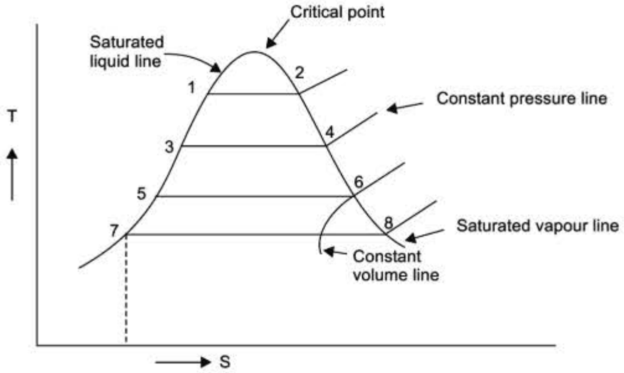


Fig. 3.6

(b) Enthalpy-Entropy Chart (Mollier Chart)

The enthalpy and entropy of the saturated liquid and vapour can be found from steam tables at various pressures. These two lines can be drawn on h–s diagram

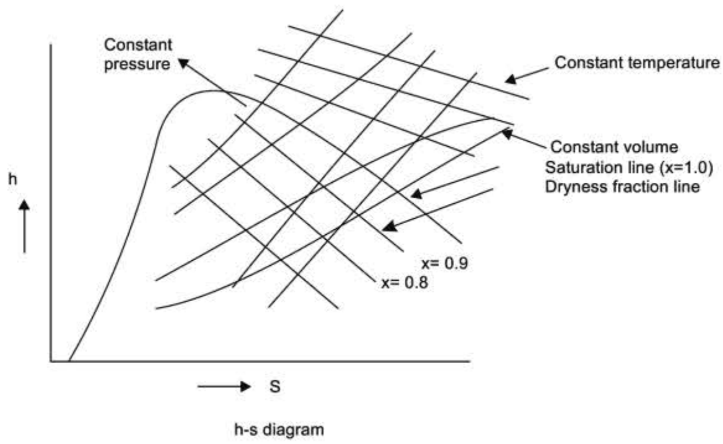


Fig. 3.7

on this chart lines of constant pressure, constant volume, constant temperature are also shown.

SOLVED PROBLEMS

Problem 1

Determine the state of the steam, i.e. whether it is wet, dry or superheated in the following cases:

(i) Pressure 8 bar and specific volume 0.196 m^3/kg.
(ii) Pressure 14 bar and temperature 225°C
(iii) Pressure 25 bar and 2700 kJ/kg of heat is required to generate steam from water at 0°C.

Solution

(i) The given value of specific volume = 0.196 m^3/kg is less than that of taken from steam table at 8 bar, i.e. 0.2402 m^3/kg.

$$\text{Dryness fraction } x = \frac{0.196}{0.2402} = \frac{0.196}{0.2402} = 0.815 \text{ Ans. (wet steam)}$$

(ii) The saturated temperature at 14 bar is 195°C which is less than the temperature of given sample. Hence, sample is *superheated* and degree of superheat = (225–195) = 30°C.

(iii) At pressure 25 bar, h_g = 2809.9 kJ/kg and for sample enthalpy is less than it. Therefore, enthalpy of wet steam = $h_f + xh_{fg}$

$$2700 = 961.9 + x1839$$

$$x = 0.945 \text{ Ans.}$$

Problem 2

Evaluate enthalpy, internal energy, volume and entropy of 1 kg of steam having dryness fraction 0.85 and pressure of 20 bar.

Solution

From steam tables at 20 bar, properties are:

t_s = 212.4°C	v_f = 0.00177 m^3/kg	v_g = 0.099549 m^3/kg
h_f = 908.6 kJ/kg	h_{fg} = 1888.7 kJ/kg	h_g = 2797.2 kJ/kg
S_f = 2.447 kJ/kgk	S_{fg} = 3.890 kJ/kgk	S_g = 6.337 kJ/kg k

Enthalpy = $h_f + xh_{fg}$

= 908.6 + 0.85 × 1888.7 = 2513.995 kJ/kg

Volume $= (1 - x)v_f + xv_g \simeq xv_g$

$= (1–0.85) \times 0.00177 + 0.85 \times 0.099549$

$= 0.0848$ m^3/kg

Internal energy $= h - Pv$

$= 2513.995 - 20 \times 10^5 \times 10^{-3} \times 0.0848$

$= 2344.395$ kJ/kg

Entropy $= S_f + xS_{fg}$

$= 2.447 + 0.85 \times 3.890$

$= 5.753$ kJ/kgk

Problem 3

In a turbine, steam expands from 20 MPa, 550ºC to 0.005 MPa isentropically. Evaluate the work done per kg of steam.

Solution: Equation

20 MPa $= 20 \times 10^6$ Pa

$= 20 \times 10^6$ N/m^2 = 200 bar.

.005 MPa $= 0.005 \times 10^6$ Pa

$=$ .05 bar

Isentropic expansion process 1–2 is shown in figure:

$S_1 = S_2$

$S_1 = S_g + C_{ps}$ In T_{sup}/T_s

value of C_{ps} is not given. However, average value of C_{ps} = 2.0934 kJ/kgk.

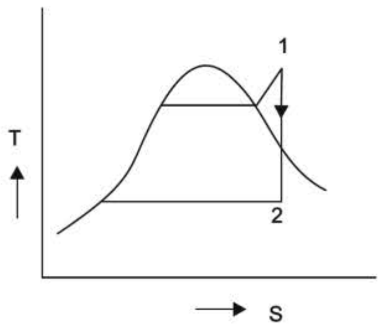


Fig. 3.8

From steam table, saturation temperature T_s = 365.7ºC at 200 bar which is less than 550ºC. Therefore, steam is superheated. So directly superheated steam table can be used for:

$$S_1 = 6.325 \text{ kJ/kgk and } h_1 = 3388.3 \text{ kJ/kg at } 0.05 \text{ bar}$$

$$S_2 = S_{f2} - xS_{fg2}$$

$$6.325 = 0.476 + x7.920$$

$$x = 0.738$$

$$h_2 = hf_2 + xh_{fg2}$$

$$= 137.8 + 0.738 \text{ x } 2423.8 = 1926.56$$

$$\text{Work done per kg} = (h_1 - h_2)$$

$$= (3388.3 - 1926.56)$$

$$= 1461.74 \text{ kJ}$$

Problem 4

Steam at 10 bar and 0.9 dryness fraction is available, find the final dryness fraction of steam in each of the following two cases:

(i) 170 kJ of heat is removed per kg of steam at constant pressure.

(ii) Steam expands isentropically to a pressure 0.5 bar in a turbine in a flow process. The turbine develops 300 kJ of work per kg of steam.

Solution

At 10 bar and 0.9 dryness,

$$\text{heat available} = h_f + x_1 h_{fg} = 762.6 + 0.9 \times 2013.6$$

$$= 2574.84 \text{ kJ/kg.}$$

If 170 kJ heat is removed, then rest heat = 2574.84 – 170 = 2404.84 kJ/kg

$$2404.84 = 762.6 + x_2 \times 2013.6$$

$$x_2 = 0.815 \text{ Ans.}$$

(ii) $$h_1 = 2574.84 \text{ kJ/kg}$$

$$300 = 2574.84 - (340.6 + x_2 \times 2305.4) \text{ at } 0.5 \text{ bar}$$

$$x_2 = 0.83$$

3.3 METHODS OF DETERMINING THE DRYNESS FRACTION OF STEAM

There are three methods used for determining the dryness fraction of steam:

(a) Separating Calorimeter

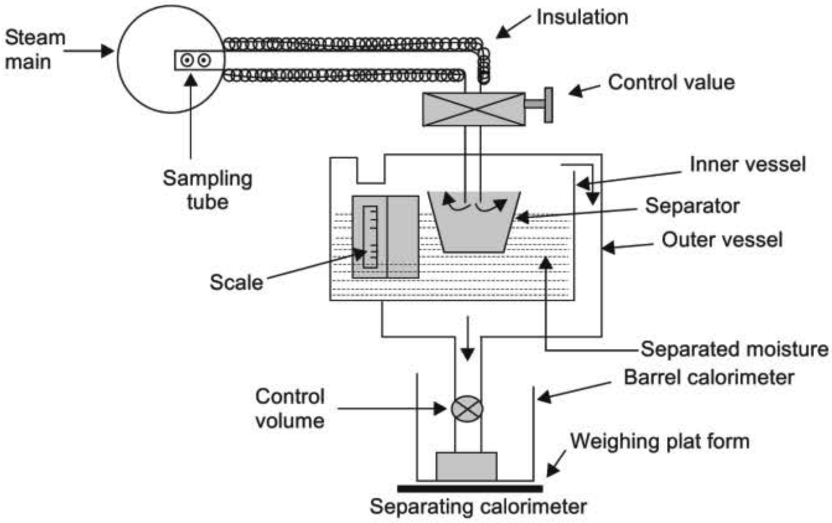


Fig. 3.9

(b) Throttling Calorimeter
(c) Combined Separating and Throttling Calorimeter

Separating Calorimeter

The apparatus used is shown in figure. The supply steam is admitted to the calorimeter from main pipe through a sampling tube. The incoming steam strikes the baffle plate and direction of steam is completely reversed. Therefore, water particles being heavier are separated and collected at the bottom of the vessel. The quantity of separated water is noted from the indicator attached with the inner vessel. The dry steam passes down through the annular space between inner and outer vessel. A barrel calorimeter rests on a weighing platform. The calorimeter receives the dry steam in the form of condensate whose quantity is obtained by weighing machine.

Let m_w = mass of moisture collected in inner vessel in kg.
m_s = mass of steam condensed in barrel calorimeter in kg.
x = dryness fraction of steam.

$$\text{dryness fraction of steam } x = m_s/m_s + m_w$$

Limitations:

(a) The size of the water particles is very small and may be carried away with the steam at high dryness fraction. Therefore, this calorimeter cannot be used for high dryness fraction of steam.
(b) Complete separation of water is not possible.
(c) Method is approximate.

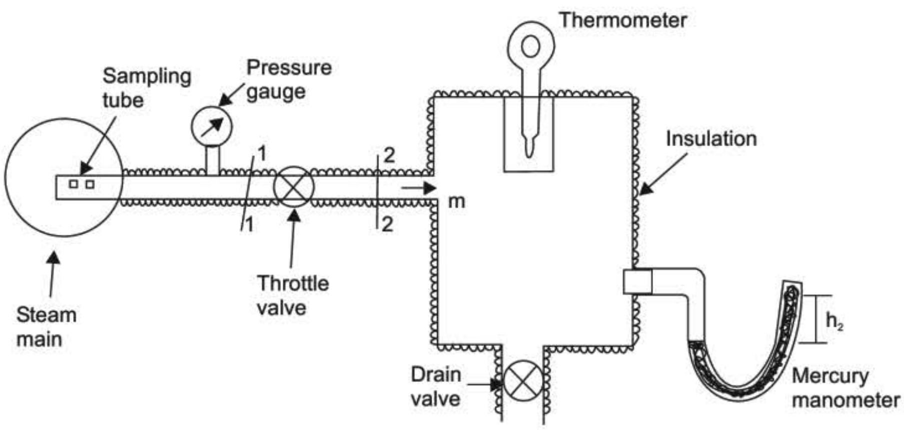


Fig. 3.10

Throttling Calorimeter

The sample of the wet steam enters through the sampling tube as shown in figure:

The sample of the steam is throttled. A pressure gauge and a mercury manometer are provided to measure pressure before and after throttling respectively. The steam after throttling must be superheated. With the help of mercury thermometer, temperature of throttled steam can be measured. During throttling, the enthalpy of steam remains constant. The enthalpy of superheated steam is known if its pressure and temperature are known. If wet steam is throttled to become superheated, then the dryness fraction can be evaluated by equating before and after throttling. The properties of steam are noted from the steam table.

Limitations:

(a) For the measurement of minimum value of dryness fraction, the steam should be superheated by minimum 5°C.

(b) This method cannot be used for low dryness fraction.

Combined Separating and Throttling Calorimeter

The arrangement is shown in figure. Steam from main pipe is collected through sampling tube. First it enters into separating calorimeter where direction is reversed and thereby heavy water particles are collected and separated at the bottom of the separator. The steam with considerable dryness fraction leaves the separator and enters the throttling calorimeter where it is collected and taken to the superheated region. The process is shown on the h–s diagram.

The process 1–2 represents separation of moisture at constant pressure. The dryness fraction x_1 at point 1 is improved to x_2 at point 2. Process 2–3 represents throttling.

Calculation of dryness fraction:

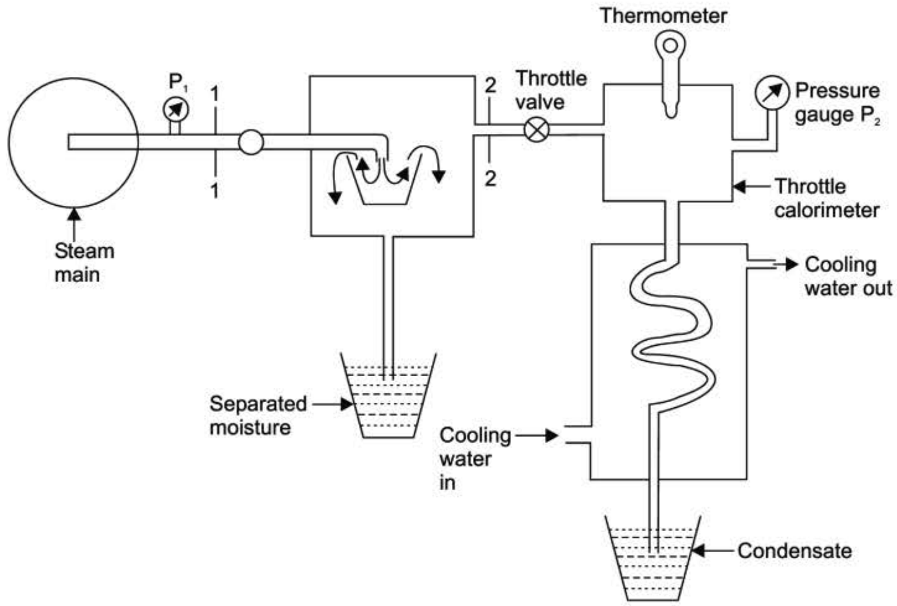


Fig. 3.11: Combined separating and throttling calorimeter

Let m = mass of steam passing through sampling tube in kg.
m_1 = mass of moisture separated in separator in kg.
ms_1 = mass of steam coming from separating calorimeter in kg.
x = dryness fraction of steam in steam main.
x_1 = dryness fraction of steam leaving the separating calorimeter.
x_2 = dryness fraction of steam leaving the throttling calorimeter.

The dryness fraction of steam after separating calorimeter is given by $x_1 = m_{s1}/m$.

It should be noted that the sample m_{s1} contains moisture m_2 and dry steam m_{s2}. Therefore, the dryness fraction after throttling is given by $x_2 = m_{s2}/m_{s1}$.

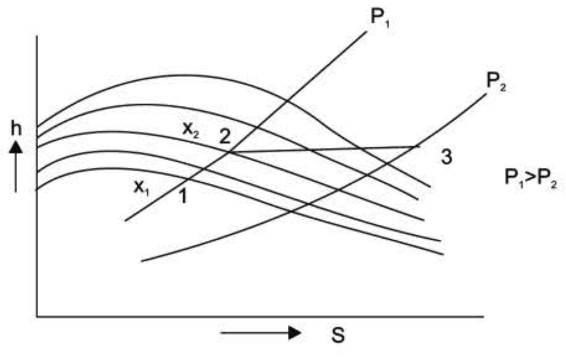


Fig. 3.12: Representation of separating and throttling processes

The total dryness fraction of steam will be the ratio of final dry steam to total initial steam given as:

$x = m_{s2}/m = m_{s2}/m_{s1} \times m_{s1}/m = x_2 \cdot x_1$

$x = x_1 x_2$

Thus, the dryness fraction of steam main is the product of dryness fractions given by separating and throttling calorimeter respectively.

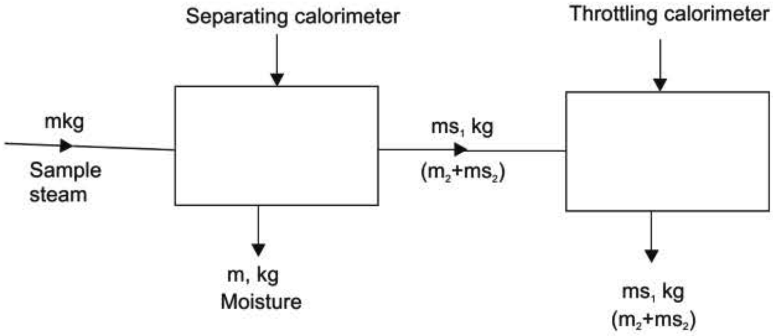


Fig. 3.13: Line diagram for calculation.

Problem 1

A sample of steam from a boiler drum at 3MPa is put through a throttling calorimeter in which the pressure and temperature are found to be 0.1 MPa, 120ºC. Find the quality of the sample taken from the boiler.

Solution

$h_f + xh_{fg} = h_g + C_p\,(t_2 - T_{sup})$ [During throttling enthalpy remains constant]

$$1008 + x \times 1795.73 = 2675 + 2.1\,(120 - 100)$$

$$= 2675 + 2.1\,(20)$$

$$x = \frac{2675 + 42 - 1008.41}{1795.73}$$

$$= \frac{1708.59}{1795} = 0.951$$

Exercise Problem

Steam flows in a pipeline at 1.5 MPa. After expanding to 0.1 MPa in a throttling calorimeter, the temperature is found to be 120ºC. Find the quantity of steam in pipeline.What is the maximum moisture at 1.5 MPa that can be determined with this set-up if at least 5ºC of superheat is required after throttling for accurate readings?

3.4 BOILER

Introduction

Steam is the most important vapour used as a working substance in steam engines and turbines working on vapour power cycles. The equipment used for producing steam is called steam generator or boiler. Technically speaking, all steam generators are not boilers but all boilers are steam generators.

Definition

Steam generator (as given by ASME) "A combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporized."

The boiler or evaporator is that part of steam generator which consists only of the containing vessel and convection heating surfaces where phase change (or boiling) occurs from liquid (water) to vapour (steam) essentially at constant pressure and temperature. Minimum capacity of the boiler should not be less than 22.4 litres. However, the term 'boiler' is traditionally used to mean the whole steam generator.

The boiler consists of a drum called shell in which water is contained. The thermal energy released due to combustion of fuel (may be solid, liquid or gas) in the combustion chamber is used to evaporate water and to produce steam at a desired pressure and temperature. The steam thus generated is used for:

(a) **Power generation:** Mechanical work or electrical power may be generated by expanding steam in steam engine or steam turbine.
(b) **Heating:** The steam is utilized for heating the residential and industrial buildings in winter season and for producing hot water for hot water supply.
(c) **Industrial Processings:** Steam is used in textile industries, sugar mills and other chemical industries.

Requirements of a Good Boiler

A good boiler should be able to fulfill the following conditions.

(1) It should be capable of generating the maximum quantity of steam at a required pressure and temperature and quality with minimum fuel consumption.
(2) It should be light in weight and should not occupy much space.
(3) It should be safe in working and should conform to the safety regulations laid down in the boiler Act.
(4) The initial cost, installation cost and maintenance cost of the boiler should be low.
(5) It should be capable of quick starting and should be able to meet any rapid fluctuation of load.

(6) All parts and components should be easily accessible for inspection and repair.
(7) It should have minimum number of joints and these too should be as far away as possible from the direct flames.
(8) The design and construction of the component parts should be such that they can be easily dismantled and transported.
(9) To make the best use of the heat supplied, the boiler should have proper arrangement of circulation of water and hot gases.
(10) Minimum refractory material should be used.
(11) The heated surface should be entirely free from any deposition of mud or firing particles.

Classification of Boilers

Boilers are classified on the basis of following:

(i) Tube contents
(ii) Method of firing
(iii) Pressure of steam
(iv) Method of circulation
(v) Nature of service
(vi) Position and number of drum
(vii) Gas passage
(viii) Nature of draught
(ix) Heat source
(x) Once through boiler
(xi) Fluid used
(xii) Boiler shell material.

(i) Tube Contents

According to the contents in the tube the boiler is classified as

(a) Fire tube boiler
(b) Water tube boiler

(a) Fire Tube Boiler

Example: Cochran, Lancashire, Cornish Locomotive boiler

In the fire tube boiler, the hot gases (flue gases) pass through the tubes and water surrounds them. The products of combustion (hot gases) leaving the furnace pass through fire tubes which are surrounded by water. Heat from hot flue gases is transferred to water which is converted into steam. The spent flue gases are then discharged to atmosphere through chimney.

(b) Water Tube Boiler

Example: Babcock and Wilcox boiler, Stirling boiler

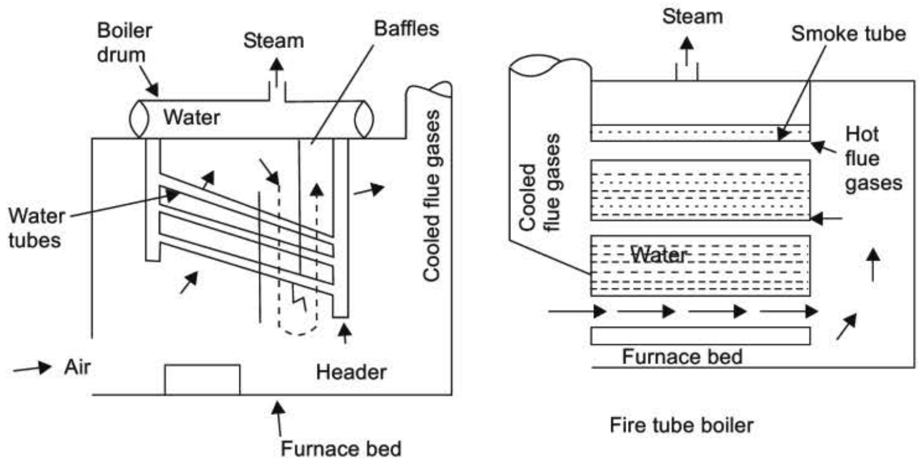


Fig. 3.14

In water tube boiler water flows inside the tube and the hot flue gases flow outside the tubes. A bank of water tubes containing water is connected with a steam water drum by means of two sets of headers. The hot flue gases from the furnances pass over the tubes and are discharged through the chimney. The water thus absorbs heat from the hot gases and evaporates in the form of steam. The steam thus formed gets accumulated in the steam space.

(ii) Method of Firing

On the basis of method of firing, boilers are classified as:

(a) **Internally Fired Boiler:** As the name implies, the furnace region is provided inside the boiler shell and is completely surrounded by water cooled surfaces. Examples of the internally fired boiler are Lancashire, Locomotive and Scotch boiler.

(b) **Externally Fired Boiler:** Furnace is provided outside the boiler. Its furnace region is simple and easy to construct. Example of externally fired boiler is the Babcock and Wilcox boiler.

(iii) Pressure of Steam

Boilers may be classified according to pressure as:

(a) **Low pressure boiler:** A boiler which generates steam at a pressure below 80 bar is called a low pressure boiler. Examples of low pressure boilers are Cochran, Cornish, Lancashire and Locomotive boilers.

(b) **High pressure boiler:** A boiler which generates steam at a pressure higher than 80 bar is called a high pressure boiler. Examples of high pressure boilers are Babcock and Wilcox, Lamont, Velox, Benson boilers, etc.

(iv) Method of Circulation of water

(a) **Natural Circulation:** In these type of boilers circulation of water in the boiler takes place by natural convection current produced by the application of heat. Examples of these are Lancashire, Locomotive, Babcock and Wilcox boilers, etc.

(b) **Forced Circulation:** In these mechanical means (pumps) are used to increase the circulation. Examples are Lamont, Velox boilers, etc.

(v) Nature of Service

(a) **Stationary boilers:** Boilers that are used for stationary plants are called stationary or land boilers.

(b) **Portable boilers:** Boilers that can be readily dismantled and transported from one place to another are called portable boilers.

(c) **Mobile boilers:** The boilers which are fitted on vehicles that can move from place to place are called mobile boilers. Examples are marine and locomotive boilers.

(vi) Position and Number of Drums

According to position

(a) Horizontal boiler
(b) Inclined
(c) Vertical

According to number of drums

- Single drum
- Multi drum

(viii) Nature of Draught

(a) Natural draught boilers
(b) Forced draught boilers

(ix) Heat Source

The heat source may be any of the following:

(a) Combustion of solid liquid or gaseous fuel.
(b) Electrical or nuclear energy.
(c) Hot waste gases which are by-products of other chemical processes.

(x) Once through Boiler

In this type of boiler, there is no recirculation of water. The feed water leaves the tube as steam. An example is the Benson boiler. In recirculation boilers only a part of water is evaporated and the remainder is circulated.

(xi) Fluid Used

On the basis of fluid used, the boilers are classified as:

- Steam boilers: In this water is the working fluid.
- Mercury boilers: In this mercury is the working fluid.

Difference between Water Tube and Fire Tube Boilers

Fire Tube Boiler	Water Tube Boiler
(i) Hot flue gases flow inside the tubes while water surrounds the tube.	(i) Water flows inside the tubes while the hot flue gases surround the tube.
(ii) It has a large ratio of water content to steam capacity and therefore slow in evaporation.	(ii) It has comparatively small ratio of water content to steam and therefore quick evaporation.
(iii) Failure in water supply is less effective and may not overheat the boiler due to large capacity of water.	(iii) Failure in water supply system brings about a breakdown as the boiler may be overheated due to low capacity of water.
(vi) The stress consideration limits the range of pressure from 17.5 bar to 24.5 bar. Thus, it is suitable for low pressure.	(iv) It can withstand high internal pressure for the same wall thickness and stress. Thus, it is suitable for pressures as high as 200 bar.
(v) It has a small capacity due to smaller heating surface area resulting in slow rate of steam generation. It is not suitable for steam power plants.	(v) It has a wide range of capacity due to larger heating surface area resulting in high rate of steam generation. It is suitable for large power plants.
(vi) Circulation is poor and thus there is every chance of a deposit of impurities on the heated surface. The construction is such that removal of impurities is difficult.	(vi) Circulation is greater thus there are less chances of a deposit of impurities on the heated surface. The construction is such that impurities if deposited from the water are found outside the zone of rapid circulation and can be easily removed.
(vii) An exposition if it occurs becomes a very serious problem in a fire tube boiler because of its large water capacity.	(vii) Because of the small drum size the water is uniformly spread in a large number of tubes, thus the failure of one water tube does not cause any disastrous explosion.
(viii) All parts are not easily accessible for cleaning, inspection or repair.	(viii) All parts are easily accessible for cleaning inspection or repair.
(ix) It is less efficient.	(ix) It is highly efficient.
(x) Though it is suitable for rapid changes in load but large load fluctuations extending over long duration may damage the boiler.	(x) It is suitable for large load fluctuations extending over long durations without danger to the boiler.
(xi) The construction is simple, rigid and compact. Hence the initial cost is less.	(xi) Design is complex hence initial cost is high and it requires periodic examinations.

(xii) Boiler Shell Material

On the basis of materials used for shell the boilers are classified as follows:

(a) Cast iron boilers
(b) Steel boilers
(c) Copper and stainless steel.

Fire Tube Boilers

Cochran Boiler: The Cochran boiler is one of the most popular and best type of vertical, multitubular, fire tube (internally fired) natural circulation boiler. The following particulars relate to a 2.75 diameter shell.

Height of the shell = 5.78 m.

Maximum evaporative capacity = 568 kg/hr of steam from cold feed when burning 36 to 40 kg/hr of coal.

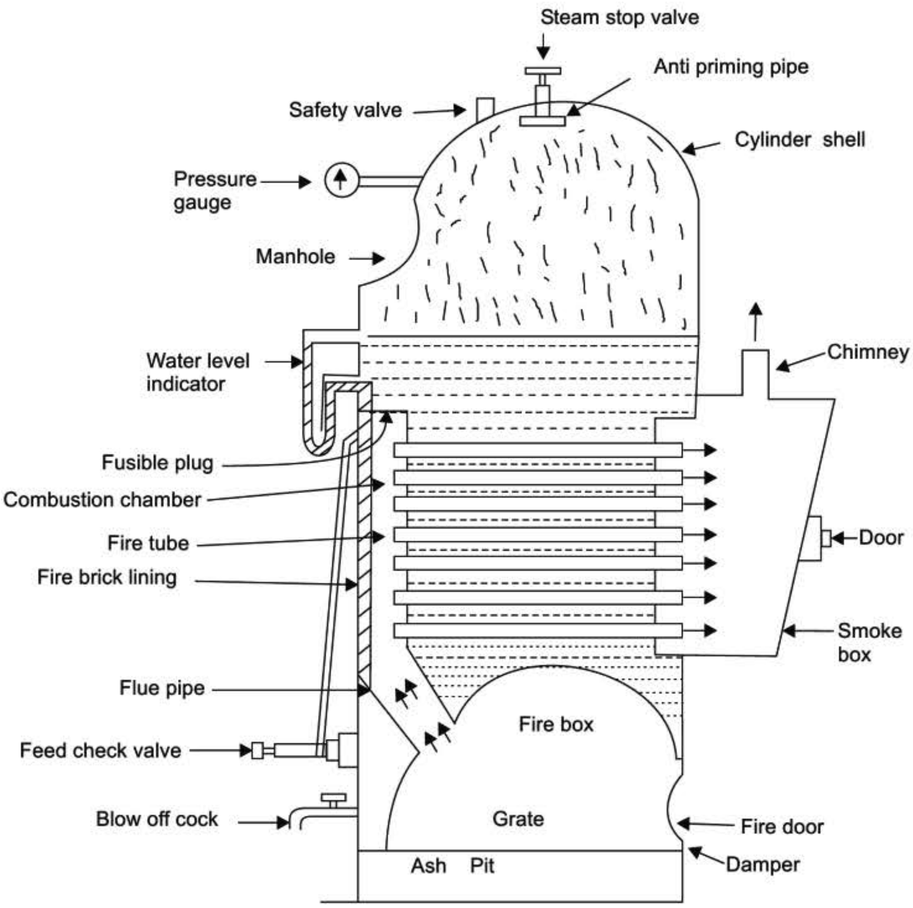
Economical rating = 3/4 of the maximum
Heating surface = 120 m^2
Steam pressure = 6.7 bar.

Construction Details: It consists of a vertical cylindrical shell having a hemispherical top. The shell is made of mild steel plates. The furnace is also hemispherical in shape and it is hydraulically pressed from one plate without a single weld or scum. Thus, the furnace is the strongest structure under compression. The fire grate is arranged in the furnace and the ash-pit is provided below the grate. In the firebox a fire door and a damper are provided. Adjacent to the fire box the boiler has a combustion chamber which is dry-baked and lined with fire bricks. Close to the combustion chamber a number of horizontal smoke tubes are provided. These tubes are of equal length and arranged in a group with wide space in between them and the shell so as to help convection currents. The ends of these smoke tubes are fitted in the smoke box tube plate and combustion chamber tube plates. These tubes are simply pushed in the holes of tube plates and then expanded at the ends to make steam light joints. The smoke box is built of steel plates and is fitted with hinged door which gives an easy access to smoke tubes for cleaning and inspecting. The stack is provided at the top of the smoke box for discharge of the gases to the atmosphere.

The furnace is surrounded by water on all sides except at the opening for the fire door and the combustion chamber. The smoke tubes are also completely surrounded by water.

Working: The hot gases produced from the burning of the fuel on the grate rise up through the flue pipe and reaches the combustion chamber. The flue gases from the combustion chamber passes through the fire tubes and the smoke box and finally are discharged through the chimney. The flue gases during their travel from fire box to the chimney give heat to the surrounding water to generate steam.

The circulation of water in the shell is shown by arrows. The water courses down by the cooler wall of the shell and rise up past the fire tubes by natural circulation due to convection current.



Cochran boiler

Fig. 3.15

LANCASHIRE BOILER

A Lancashire boiler is fire tube boiler. Its normal working pressure range is 15 bar and steaming capacity is about 8000 kg/hr. Its size varies from about 8 metres to 9 metres in length and from 2 to 3.5 metres in diameter.

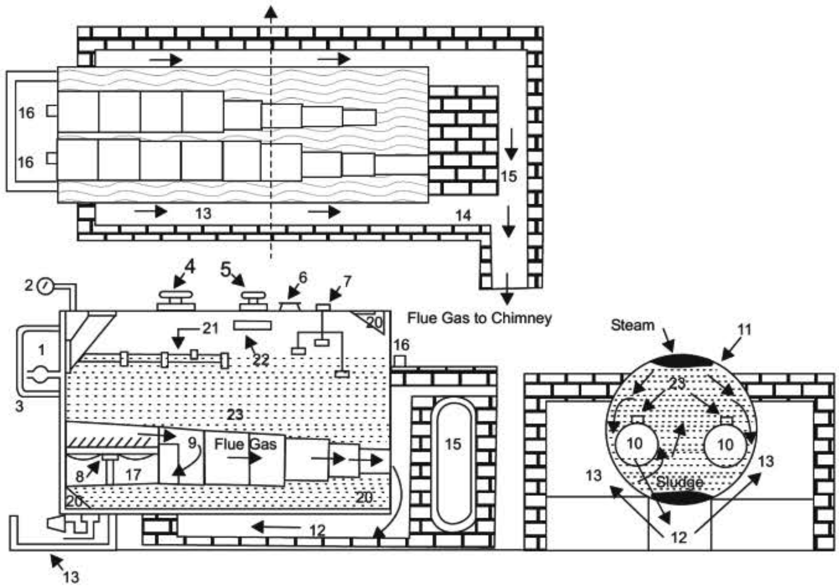
Constructional details: It consists of the following parts.

(1) **Feed check valve:** Feed water is supplied to the boiler under pressure, feed check valve stops its escaping back.

(2) **Pressure gauge:** It is used for measuring the pressure of steam.

(3) **Water level gauge:** It indicates the level of water in the boiler.

(4) **Dead weight safety valve:** It is for safety against pressure in excess of the rated pressure.



1. Feed check valve, 2. Pressure gauge, 3. Water level gauge, 4. Dead weight safety valve, 5. Steam stop valve, 6. Main hole, 7. Low water high steam safety valve, 8. Fire grate, 9. Fire bridge, 10. Flue tubes, 11. Boiler shell, 12. Bottom flue, 13. Side flue, 14. Dampers, 15. Main flue, 16. Doors, 17. Ashpit, 18. Blow off cock, 19. Blow off pit, 20. Gusset stays, 21. Perforated feed pipe, 22. Anti primming pipe, 23 Fusible plug.

Fig. 3.16

(5) **Steam stop valve:** It opens and closes the supply of steam for using.

(6) **Manhole:** It is for cleaning and inspection of the drum.

(7) **Fire grate:** The grate in which the solid fuel is burnt.

(8) **Fire bridge:** This is used for deflecting the gases of combustion upwards.

(9) **Flue tubes:** These are for the first pass of the flow of the flue gases. The flue tubes are tapered being larger in diameter at the front and smaller at the back.

(10) **Boiler shell:** It is used for containing water and steam.

(11) **Damper:** It is used for controlling the flow of flue gases. These are iron doors which slide up and down in the grooves by rope and pulley.

(12) **Blow off cock:** Blow off cock is provided at the bottom of the shell by a bent pipe to blow off sludge at intervals. Since the water shell is not perfectly horizontal, a few degrees tilting towards the front enables all the sediments to accumulate in front near the blow off cock.

(13) **Anti priming devices:** It is for separating out suspended moisture and allowing as far as possible the dry steam through the stop valve.

(14) **Fusible plug:** It is for safety against exposing the fuel tube to excessive heat when the water level falls too low.

Working Process

The fuel is burnt on the grate and as a result hot combustion gases (flue gases) are produced. As soon as the flue gases reach the back of the main flue they deflect downwards and travel through the bottom flue. The bottom flue is situated below the water shell and heats the lower portion of the shell. After travelling from back to the front, these flue gases bifurcate into separate paths inside flues. Now they travel from front to back in the side flues and thus heat the side of the water shells.

After these two steams of the flue gases meet again the main flue passing through damper from where they are discharged to atmosphere through the chimney. The damper controls generation of steam. A Lancashire boiler can take overloads and meet demand at falling pressure. For short duration overloads, the pressure of steam can be maintained by reducing the feed water supply. In this way a boiler will generate wet or dry saturated steam. To generate superheat steam, a superheater (boiler accessory) will have to be incorporated.

Uses

Lancashire boiler is used in sugar mills and chemical industries where along with power, steam is also required for process work.

Locomotive Boiler

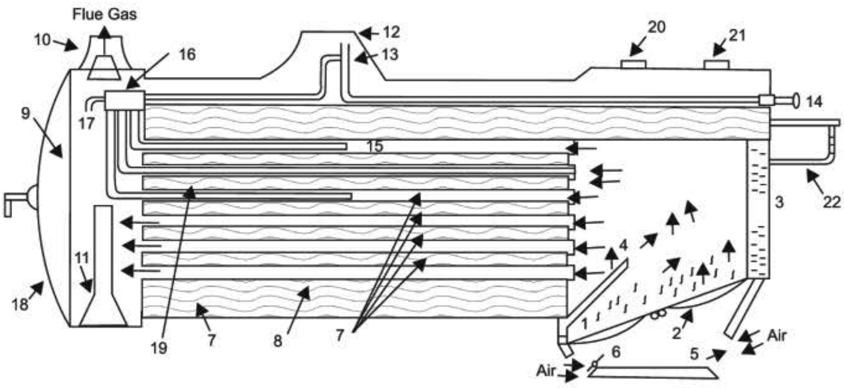
The locomotive boiler is a horizontal, multitubular, natural circulation, artificial draft, internally fired, fire tube type of portable boiler. The unit is so designed that it is capable of meeting the sudden and fluctuating demands of steam which may be imposed because of variation of power and speed. In addition to railways road rollers and haulage engines, the locomotive boilers have been used in agricultural fields, saw mill plants and stationary power service where semi-portability is desired.

The principal parts of the unit are:

(1) **Fire box:** This forms a combined grate and combustion chamber. The fire box is water cooked on all the three sides except the bottom.
(2) **Mutitubular barrel:** It contains an envelope of water in which fire tubes are immersed.
(3) **Smoke box:** It is equipped with a very short chimney.

Working

The coal is burnt in the fire box and produces the hot flue gases. These flue gases rising from the grate are deflected upwards by a fire bridge and so that it comes into contact with the walls and roof of the firebox. Due to the motion of the locomotive, a strong draught is created and the atmospheric air rushes into the fire-box through the dampers. The function of the dampers is to control the quantity of air entering in the fire box. The ash of the coal burnt on the grate falls into the ash-pit. The hot flue gases pass from the furnace box to the smoke box through horizontal smoke tubes. A large door in the front of the smoke box gives access to



1. Firebox	2. Grate	3. Fire hole
4. Fire bridge arch	5. Ash pit	6. Damper
7. Fine Tubes	8. Barrel or shell	9. Smoke box
10. Chimney (short)	11. Exhaust steam pipe	12. Steam dome
13. Regulator	14. Lever	15. Superheater tubes
16. Superheater header	17. Superheater exit pipe	18. Smoke box door
19. Feed check valve	20. Safety valve	21. Whistle
22. Water gauge		

Fig. 3.17: Locomotive boiler.

it and the tubes for examination and cleaning purposes. The hot gases from the smoke box are discharged to the atmosphere through a short chimney.

During the travel of hot gases from the grate to the chimney, they give heat to the water and generate steam. The generated steam is collected in the steam dome. The function of steam dome is to increase the steam release capacity and to increase the distance of steam from water line which reduces priming. The driver operates the regulator by turning a lever which leads the dry saturated steam to the engine for expanding and doing work. To get superheated steam, the steam is diverted to superheated heater with the help of a regulator and lever arrangement and then to superheater tubes. They start from the superheater header and are laid inside the large diameter fire tubes which are placed at the highest of the boiler shell. The hot flue gases passing through the fire tube supply heat to the superheater tube that heat the steam inside superheater tubes which get superheated steam.

Babcock and Wilcox Boiler

Babcock and Wilcox boiler is a water tube high pressure boiler. This is used for large generation rate at high pressure. The boiler has three main components– steam and water drum, water tubes and furnace.

It is a longitudinal drum, externally fired water tube natural circulation type of stationary boiler. Since the boiler is externally fired, it is suitable to all types of fuels and for hand and stroker firing. Evaporative capacity in such boiler ranges from 20,000 to 40,000 kg/hr of steam and operating pressures from 11.5 to 17.5

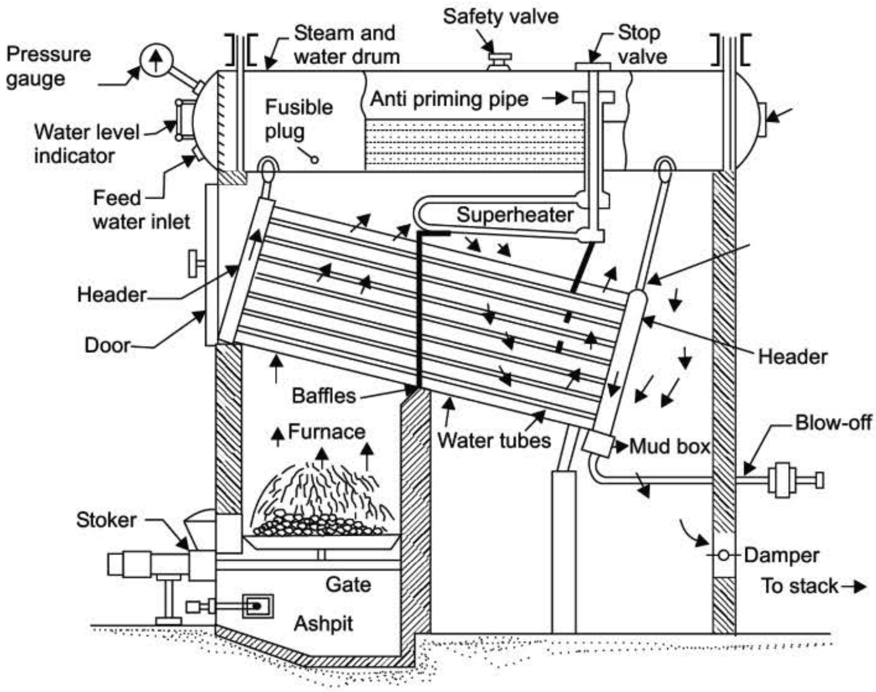


Fig. 3.18: Babcock and Wilcox boiler

bar are quite common. But the operating pressures may be as high as 42 bar. It is suitable for small size thermal power plants and other industrial works.

Construction: It consists of a high pressure-drum mounted at the top. The drum of the boiler is made of welded steel or single course joined by longitudinal butt strap. The heads of the drum are forced by hydraulic press and are dished to a radius equal to the diameter of the drum. From each end of the drum, connections are made with the upper header and down take header. A large number of water tubes connect the uptake and down take headers. The water tubes are inclined 5 to 15 degrees to promote water circulation. The water tubes are straight, solid drawn steel tubes about 10 cm in diameter and are expanded into the bored holes of the headers to ensure proper fixing. The headers have a serpentine (sinusoidal) form. This serpentine form of headers arranges the water tubes such that they are staggered and this exposes the complete heating surface to flue gases. The heating surface of the unit is the outer surface of the tubes and half of the cylindrical surface of the water drum which is exposed to flue gases. A mud box is attached to the bottom of the downtake header.

The whole of the assembly of water tubes is hung along with the drum from steel girder frame by steel rods called slings in a room made of masonry work lined with fire bricks. Below the uptake header the furnace of the boiler is arranged. The coal is fed to chain grate stoker. There is a bridge wall deflector which deflects the products of combustion upwards. Two baffles are also arranged which provide three passes of the flue gases. A damper is placed at the inlet of the chimney to regulate the draught.

Working Process

The hot combustion gases produced by burning of fuel on the grate rise upwards and are deflected by the bridge wall deflection to pass over the front portion of the water tubes and drum. In this way they complete the first pass and provision of baffles deflect the gases downwards, so that they complete the second pass. Again due to the provision of baffles they rise upwards and complete the third pass and finally come out through the chimney. During their travel they give heat to water and steam is formed. The circulation of water in boiler is due to natural circulation set up by convection currents.

Feed water is supplied by a feed water inlet pipe. The hottest water and steam rise from the tubes to the uptake header and then through the riser it enters the boiler drum. The steam vapours escape through the water to upper half of the drum. The cold water flows from the drum to the down take header and thus the cycle is completed. A set of superheater coils are provided to superheat the steam, which enters these tubes from the steam space in the boiler shell, through the saturated steam box. The superheated steam is taken to the steam stop valve through the steam pipe, which is connected to superheated steam box.

BOILER MOUNTINGS AND ACCESSORIES

For safe and efficient operations, boilers are equipped with two categories of components such as:

(a) Boiler mountings.
(b) Boiler accessories

(a) Boiler mountings: Boiler mountings are those machine components which are mounted over the body of the boiler itself for the safety of the boiler and for complete control of the process of steam generation. These mountings form an integral part of the boiler. According to the Indian boiler regulations, the following mountings should be fitted on the boiler.

(i) Two safety valves
(ii) Two water level indicators
(iii) Pressure gauge
(iv) Fusible plug
(v) Steam stop valve
(vi) Feed check valve
(vii) Blow off cock

(viii) Inspector's test gauge
(ix) Man and mudholes.

(b) Boiler accessories are those machine components which are installed either inside or outside the boiler to increase the efficiency of the plant and or to help in the proper working of the plant.

The following accessories are generally used in the boiler.

(i) Air pre-heater
(ii) Economiser
(iii) Superheater
(iv) Feed pump
(v) Steam trap
(vi) Steam separator
(vii) Pressure reducing valve

Boiler Mountings

Safety Valve: Safety valves are needed to blow off the steam when the pressure of the steam in the boiler exceeds the working pressure. These are placed on the top of the boiler. There are four types of safety valves.

(1) Dead weight safety valve
(2) Spring loaded safety valve
(3) Lever safety valve
(4) High steam and low water safety valve.

Dead weight safety valve: In this valve, the steam pressure in the upward direction is balanced by the downward force of the dead weight acting on the valve. In this the weight in form of cylindrical cast iron discs is placed on the valve. The valve is made up of gun metal and it rests on a gun metal seat secured on the top of a vertical cast iron pipe bolted to the mounting block, which is riveted to the top of the boiler shell. At normal conditions the upward force exerted by steam in the boiler is balanced by the downward force equivalent to the load on the valve. When this load is greater than the force due to steam pressure acting on the valve, the steam will not escape, but in case it is less than the force due to steam pressure the valve is lifted up from its seat and the steam will escape to the enclosed discharge pipe which is connected to the discharge casing, from where it is directed outside the boiler house.

Uses

(1) Stationary boilers but not for marine portable boiler because of its great weight and reduction in effectivity when the ship is in midst of heavy waves.
(2) Used for low pressure boiler.
(3) It cannot be easily tampered.

Spring Loaded Safety Valve

Here the dead weight is replaced by a spring. It consists of cast iron body which has two valve chests for the flow of steam. The flange of the body is bolted to a mounting block on the boiler shell. There are two valves made of gun metal of the same size and they have their seats in the upper ends of the hollow valve chests. The valves are held down on their seat against the steam pressure by applying load on the valve through spring and lever arrangement. The lever has two pivots one is pinned to the lever while the other is forged on the lever. The pivots rest on the centres of the valves. The lever is pulled downwards by the spring and one half of this force is shared by each of the valves because the upper end of the spring is fixed to the lever midway between the valves. This valve has certain advantages which are listed below:

(1) The heavy weights are eliminated.
(2) Easy maintenance and examination.
(3) Suitable for marine and locomotive engines.

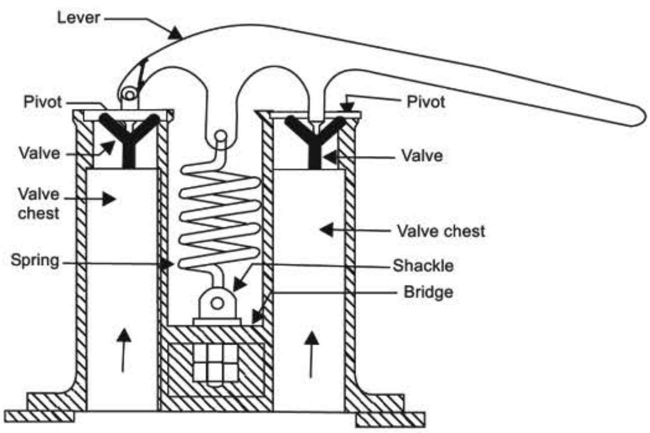


Fig. 3.19: Spring loaded safety valve

Lever Safety Valve

It consists of a cast iron body, the flange of which is bolted to the boiler mountings so as to keep it in communication with steam in the boiler.

It has a gun metal valve and valve sheet. The valve is held by a mild steel or wrought iron lever fulcrumed at one end and loaded at the other end by an external weight. The thrust is applied to the valve through a strut placed very near to the fulcrum and hinged to the lever.

The position of the weight on the lever can be fixed according to choice which will be determined according to steam pressure below the valve. The weight

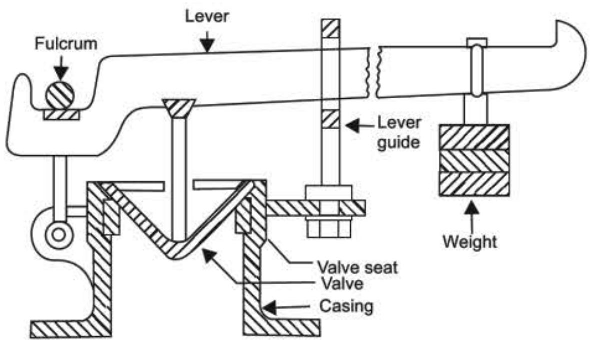


Fig. 3.20: Lever safety valve

is firmly screwed to the lever by a pin and locked so that not unauthorised person can displace it. The weight is applied at the longer arm of the lever so a small weight can give a larger thrust at the valve.

High Steam and Low Water Safety Valve

The boiler has not only to be safeguarded against too high a pressure but also against too low a water level in the boiler. We know that if the water level becomes too low, there is danger of overheating and softening of combustion chamber, furnace and other boiler parts. All this may ultimately lead to boiler explosion.

In this case we use a safety device which allows the steam to escape automatically, once the level of water falls below a certain limit. Along with that we use high-pressure safety valve which automatically discharges the steam out when the pressure of steam rises above the normal boiler working pressure.

Figure shows a high steam and low water safety valve.

It consists of two valves V_1 and V_2. The valve V_2 rests upon the valve seat and valve V_1 which is of hemispherical shape is placed over valve V_2 which acts as a valve seat for valve V_1. To safeguard against high pressure it acts as a simple lever safety valve loaded by two weights, one attached to lever and other to valve V_1. The valve V_2 is attached to external lever. The lever is hinged at its one end and a weight is at the other end. A short pivot attached on the lever is placed on the valve which keeps it in position under normal working pressure. If the pressure exceeds the normal limit, the valve V_2 opens and the steam escapes through the passage between the valve seat and the valve V_2.

The low water safety arrangement is inside the boiler. A lever is hinged from the boiler shell. At one end of the lever is a weight W_1 and at the other end of the lever a large float is provided. The hemispherical valve V_1 is connected with a spindle, the lower end of which also carries weight W_2. The knife edge provided on the lever touches a collar on the spindle under normal pressure. Now when the water level falls below a certain level the float is uncovered causing an increase in its weight according to Archimedes' principle which causes a swing in the lever.

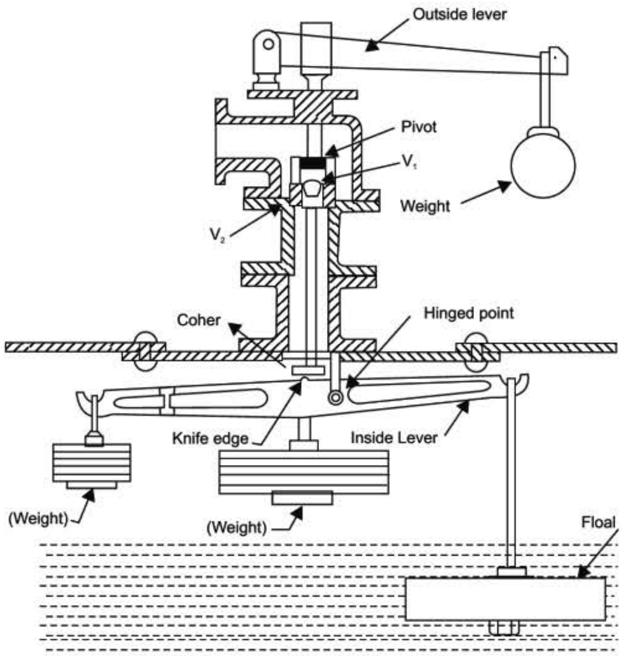


Fig. 3.21: High steam low water safety valve.

This swing pushes the spindle upwards through knife edge collar arrangement and the valve V_1 opens, steam escapes between the passage between the valves V_1 and V_2 . This produces a large hissing sound which will draw attention of the boiler attendant about the low water level in the boiler.

Water Level Indicator

The function of the water level indicator is to show the level of water in the boiler. The upper end of the valve opens in the steam space while the lower end opens in the water. The valve consists of a strong glass tube. The ends of the tube pass through stuffing boxes formed in the hollow castings. These castings are flanged and bolted to the boiler. It has three cocks, two of them control the passages between the boiler and the glass tube while the third one (the drain cock) remain closed. Two balls are provided, one is to stop the flow of water and another to stop the flow of steam. Both the balls move to the end passage as shown by dotted (ball) to stop the flow of water and steam when the water gauge glass tube is broken.

Pressure Gauge

It shows the pressure of the steam formed at any instant. The pressure generated should be nearly constant and should change with the fluctuations of load. Figure shows the details of the Bourdon's pressure gauge. The gauge is actuated by the

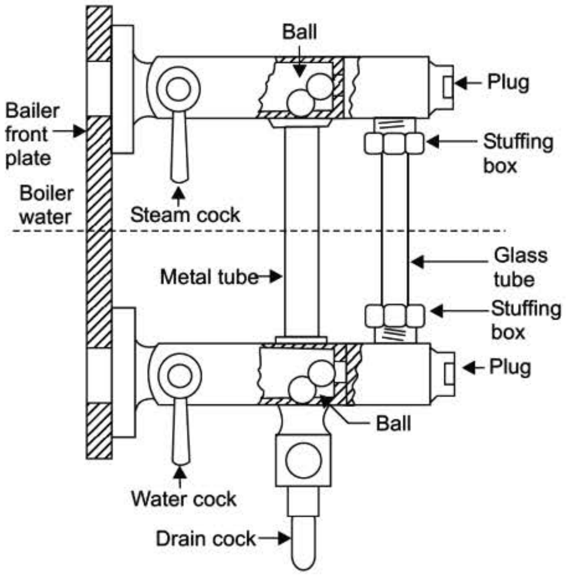


Fig. 3.22: Water level indicator

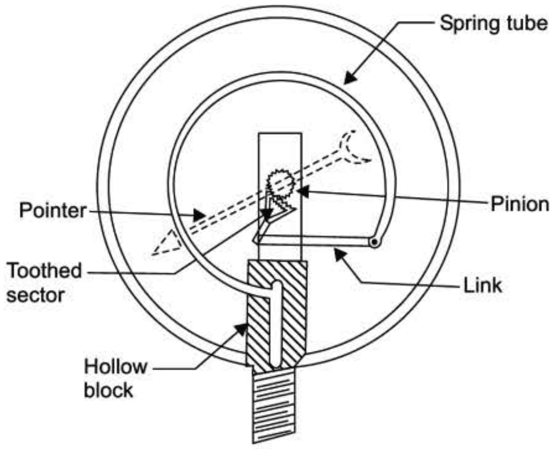


Fig. 3.23: Pressure gauge

Bourdon's tube. One end of this solid drawn elliptic section is connected to the steam space and the other end is plugged and is connected to the clock-work mechanism of the gauge. When pressure is applied to the interior of the Bourdon tube, the Bourden tube tends to straighten and move outwards. In doing so it causes pressure on the link which operates the toothed sector. Design of link mechanism is done in such a way that a slight movement of link is magnified and the pointer gives a deflection which is read on the calibrated scale.

Steam Stop Valve or Junction Valve

The function of the steam stop valve is to stop or allow the flow of steam from the boiler to the steam pipe or from the steam pipe to the turbine (or engine). Conventionally the smaller sizes are called stop valves and large sizes are called junction valves. When this valve is mounted on the topmost portion of the boiler drum, it is customary to call it a junction valve. When it is mounted in the steam pipe leading to the steam turbine or engine it is customary to call it a steam stop valve.

It consists of a valve chest made of cast iron which has two flanges at right angles. One flange is bolted to the mounted block at the highest point of the steam space and second flange is bolted to the steam pipe. A valve seat made of gun metal is screwed on the valve chest by means of logs. A gun metal valve seat is made in the chest. A valve made up of gun metal rests on the valve seat. The valve is connected to the spindle by a nut lower end of which comes in contact with a collar on the lower end of the spindle. By this construction the spindle can rotate freely in the valve but at the same time it carries the valve with it when raised or lowered. The spindle has a hand wheel at the top end by which it is rotated. The spindle passes out of a gland and stuffing box formed in the cover of the body.

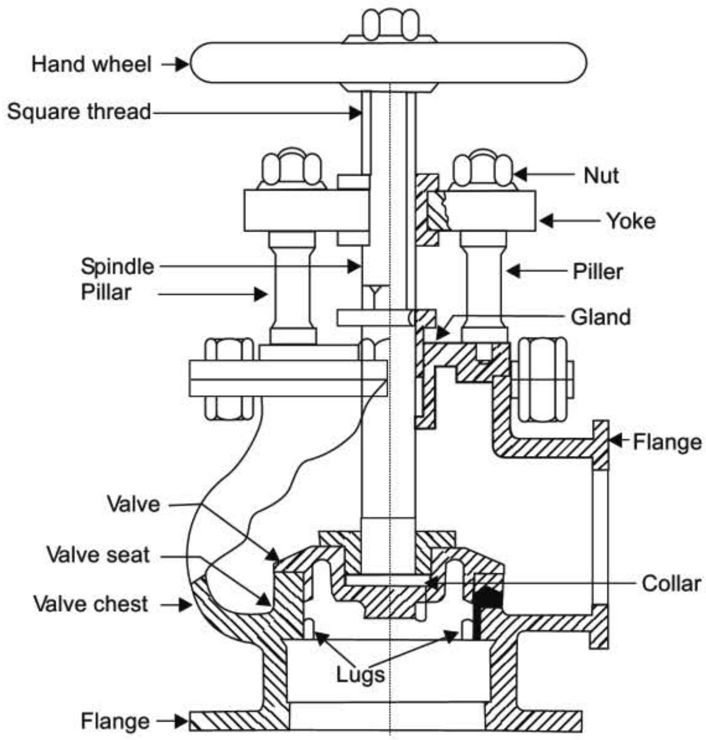


Fig. 3.24: Steam stop valve

The upper portion of the spindle has screw threads which passes through a nut in a yoke. The yoke is carried by two pillars fixed to the body.

Feed Check Valve

This valve is fitted to the boiler slightly below the working level of the water. The function of the feed check valve is to allow the feed water under pressure to pass into the boiler and to prevent simultaneously any water escaping back from the boiler in the event of failure of the feed pump.

The feed check valve consists of a check valve whose lift is controlled by the lower end of a spindle. The valve rests on its seat and is operated by the difference of pressure of water acting on its top and bottom side. The valve can be kept in a closed position by pressing it down by the spindle which can be lowered or raised by the hand wheel. Thus, the valve also carries out the function of a feed valve. This type of valve has one disadvantage that the check valve cannot be inspected or cleaned while the boiler is working.

An another design in which a separate check valve is placed over and above the check valve and the feed valve is connected to the spindle. The feed valve is placed near the boiler. Therefore, when it is closed, the boiler water pressure cannot act on the check valve and the check valve can be removed for inspection or cleaning when feed valve is closed.

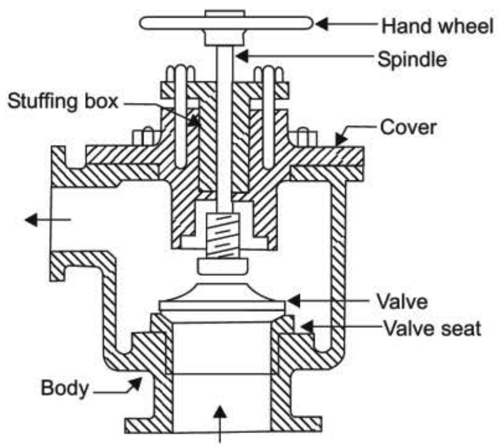


Fig. 3.25: Feed check valve

Blow off Cock

The function of blow off cock is:

(i) To remove periodically the sediments (mud, scale or other impurities) collected at the bottom of the boiler while the boiler is working.
(ii) To empty the boiler when it is to be cleaned or emptied.
(iii) To lower the water level rapidly in case the level becomes too high.

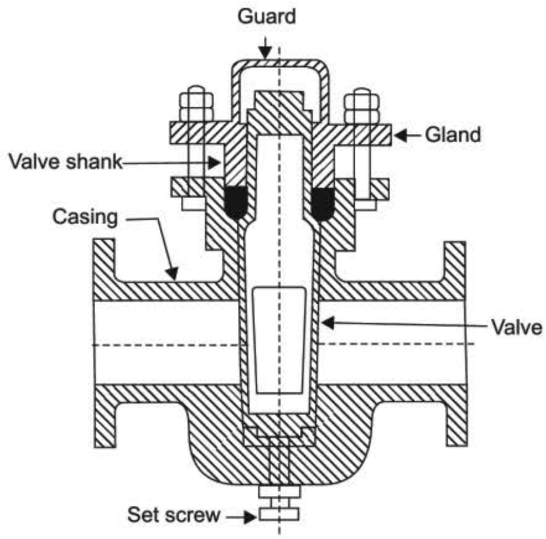


Fig. 3.26: Blow off cock

The blow off cock consists of a conical, hollow gun metal plug type valve which fits accurately into a corresponding hole in the casing. The plug valve has a hole which when brought in line with the hole in the casing by turning the plug value water will flow out of the boiler. The flow of water can be stopped by turning the plug such that its solid part comes in line with the hole in the casing .

The plug valve shank projects out of the stuffing box gland. The stuffing box is provided to prevent the leakage of water at the shank. The gland can be tightened by the nuts provided. A set screw is provided under the plug to force it off its seat, if jammed. The casing has two flanges. The blow off cock is connected to boiler by one flange and the other flange is connected to the pipe carrying the blow off water out of the boiler house.

Manhole

The function of manhole is to provide an opening through which a man can enter a boiler for cleaning and inspection purposes. Generally, it is oval in shape and a cover is provided at the top. The size of the manhole is usually 40 cm × 30 cm.

Fusible Plug

The function of the fusible plug is to extinguish the fire in the furnace of the boiler. When the water level in the boiler falls below the safe limit thereby preventing the boiler from explosion as a result of overheating of the firebox crown plate or fire tubes.

It consists of a hollow gun metal body screwed into the firebox crown plate. This body has hexagonal plane for fixing it in position with the help of a spanner.

A gun metal plug A is screwed into the upper portion of the gun metal body with the help of a hexagonal flange provided in plug A. There is another solid plug B made of copper with a conical top and rounded bottom which is kept in the hole of plug A and held firmly by putting fusible metal between them. The fusible metal may be of tin or lead which has low fusing point. Under normal working conditions the fusible plug is submerged in water, fusible metal is protected from direct contact with water or steam or furnace gases being placed between the gun metal plug A and the copper plug B. Thus, the temperature of the fusible metal is below its melting point.

When the water level falls below a certain limit in the boiler the fusible plug is uncovered out of water and is exposed to steam. This overheats the plug, with the result that the fusible metal melts and the copper plug B released and rests with the gun metal body by the ribs. This opens a way between steam space and furnace thus water and steam rush to the firebox and extinguish the fire. Before starting the boiler again, the operator fixes a new fuse.

Boiler Accessories

The boiler accessories are provided to increase the efficiency of a boiler. The following accessories are commonly attached to boilers:

(a) Air preheater
(b) Economiser
(c) Superheater
(d) Feed pump
(e) Injector
(f) Steam trap
(g) Steam separator.
(h) Pressure reducing valve.

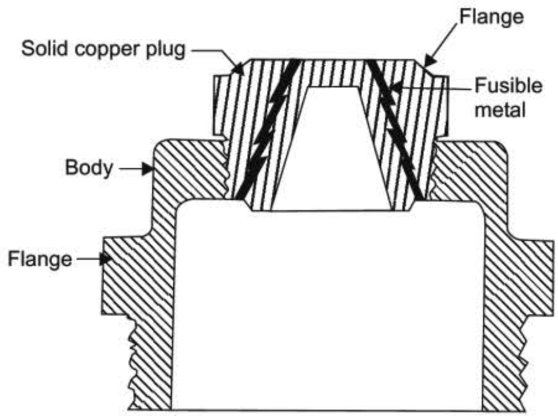


Fig. 3.27: Steam stop valve

Air Preheater

Air preheater is the waste heat recovery device which is placed in the path of the waste flue gases going to the chimney thereby abstracting heat from the flue gases and transferring it to the air before its use for economical combustion: hence the name is preheater. It is placed near the chimney and above the economiser.

The preheating of air facilitates the burning of poor grades of fuel, thus permitting a reduction in excess air and so improving the efficiency. The increase in overall efficiency of the boiler varies from 2 to 10 per cent.

Usually there are three types of preheater.

(i) Tubular
(ii) Plate type
(iii) Regenerative type

Economizer

The function of the economizer is to recover some of the heat from the heat carried away in the flue gases up the chimney or stack and to utilize it for heating the feed water supplied to the boiler. It is placed in the path of the flue gases in between the exit from the boiler and entry into the chimney.

Advantages

(1) The economiser reduces the temperature differences in the boiler and prevents the formation of stagnation pockets of cold water. Thus, it helps to reduce the thermal stress created in the boiler tubes. It also helps to improve internal circulation of water substance. For every 6°C rise in feed water temperature the gain is near about 1%.
(2) It reduces the fuel consumption in boiler furnace.
(3) The economiser helps to reduce the scale formation in boiler tubes, as most of the impurities which create temporary hardness are deposited on the inside of economizer tubes.

Working

The feed water from the feed pump on its way to the boiler enters the bottom heater. From the bottom header water passes inside the vertical tubes and reaches the upper header. From the upper header the water enters the boiler through the feed check valve. There are two stop valves for water. One is connected to the bottom header to stop or allow water to enter the economiser and the other is connected to the top header to allow or stop the water from going to the boiler from economiser. The water while passing inside the vertical tubes gains heat from the hot flue gases which passes over the vertical tube.

Soot that is deposited over the vertical tube is scraped by scrapers which are kept slowly moving up and down to clean the surfaces.

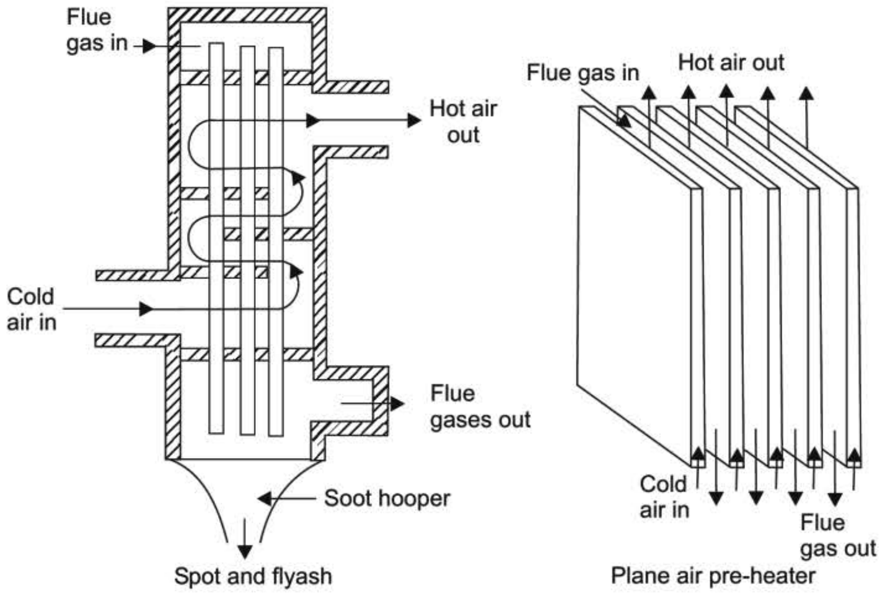


Fig. 3.28: Tubular air pre-heater

Superheaters

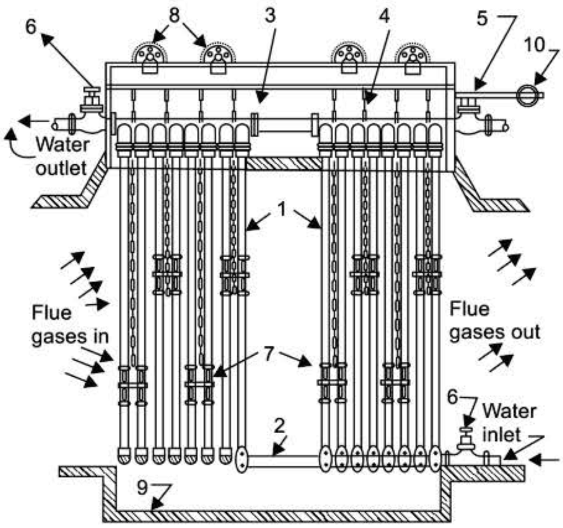
In superheater the temperature of steam is increased above saturation temperature keeping its pressure constant. This superheated steam improves the efficiency of boiler by reducing the steam consumption by producing more work per kg of steam, by reducing the condensation losses, and by eliminating the erosion of steam turbine blades. The wet steam flows inside the tubes and the hot flue gases flows over the tubes. By this way the wet steam takes heat from the flue gases and first get dried at the same temperature and pressure then its temperature is raised above the saturation temperature at the same pressure. According to the mode of heat reception, the superheaters are classified as:

(i) Convective superheaters
(ii) Radiant superheaters
(iii) Combination superheaters.

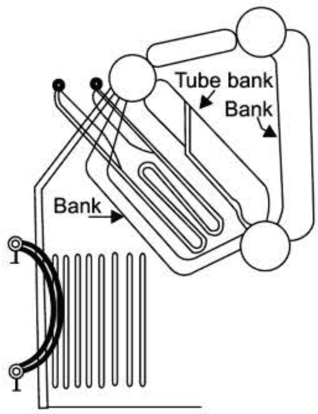
Feed Pumps

The function of the feed pump is to pump the feed water to the boiler. The three types of feed pump commonly used are reciprocating, rotary and injector pumps.

The rotary pumps are generally high speed centrifugal type and are driven either by small steam turbine or electric motor. A rotary pump is used when a large quantity of feed water is to be supplied to the boiler. In the reciprocating pump, the pumps are continuously run by the steam from the same boiler to which the water is to be fed.



Green's Economizer



Location of convection and radiant wave

Fig. 3.29

Duplex Feed Pump

It is a double acting reciprocating type feed pump. It consists of two pumps mounted side by side. One is a water pump and other is a steam pump. Both the cylinders are connected to its own piston rod which is finally connected to a common cross head so that the steam pump also serves as driver of the water pump due to the expansion of steam in the steam cylinder.

Steam Injector

An injector is a device which is used to deliver feed water into the boiler under pressure. It consists of a group of nozzles so arranged that the steam expanding in these nozzles imparts its kinetic energy to a mass of water.

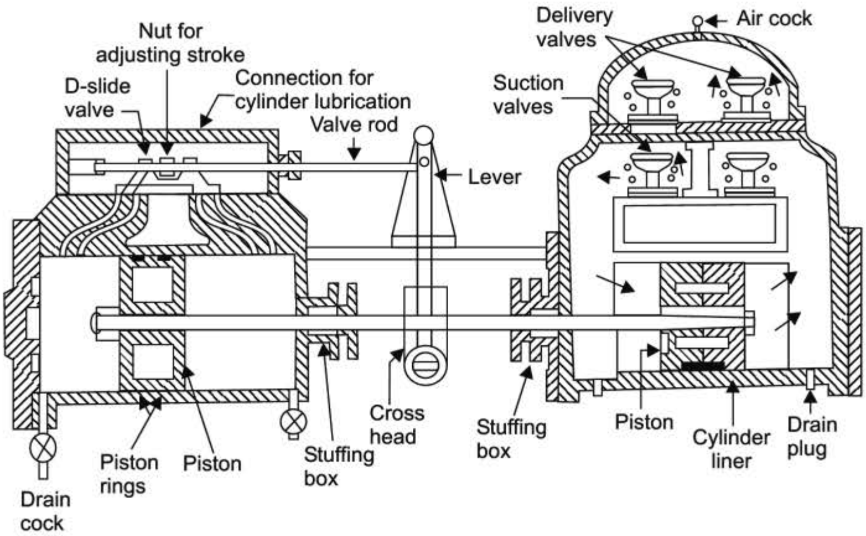


Fig. 3.30: Duplex feed pump

Construction and Working

The steam coming through the steam pipe operated by a valve enters the steam chamber, the outlet of which is in the form of a converging nozzle called a mixing tube. Inside the steam chamber there is a converging nozzle whose annular opening may be adjusted by a valve attached to the spindle operated by a hand wheel. In the nozzle section the velocity of the steam increases forming a jet of steam while the pressure decreases. Due to decrease in pressure of steam at the exit of the converging nozzle than that of feed water tank the feed water enters through the pipe. The resulting jet of water mixes with water in the mixing tube. The steam condenses and a strong vacuum is created in the mixing tube and the mixing chamber. Because of this, more water rushes from the feed tank to the mixing chamber. The velocity at the end of the mixing tube is the greatest and in the mixing chamber itself there is only high velocity jet of water. This jet of water enters the diverging cone where the kinetic energy of water is converted into pressure energy. The increase in pressure of water is sufficient to force the water into the boiler through feed check valve.

Steam Trap

The function of steam trap is to drain off water resulting from partial condensation of steam from steam pipes and jackets without allowing the steam to escape through it.

There are two types of steam traps:

(1) Bucket or float type
(2) Thermal expansion type.

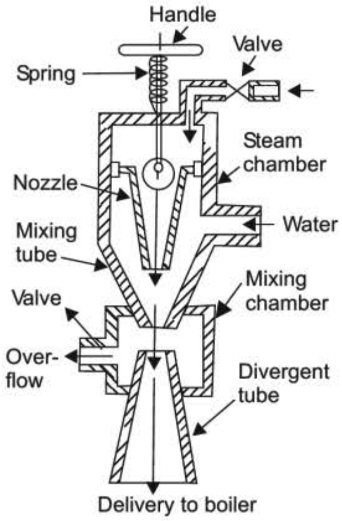


Fig. 3.31: Steam injector

Steam Separator

The function of a steam separator is to separate suspended water particles carried by steam on its way from the boiler to the engine or turbine. It is installed in the main steam pipe very near to the engine or turbine.

Pressure Reducing Valve

The function of a pressure reducing valve is to maintain constant pressure on its delivery side of the valve irrespective of fluctuating demand of steam from the boiler.

Antipriming Pipe

An antipriming pipe is a cast iron box which is fitted in the steam space of the boiler shell and under the mounting block on which the steam stop valve is to be bolted. When the steam with water particles passes through the perforations made in the upper half of the antipriming pipe, the heavier water particles separate out and are collected at the bottom of the pipe. The water thus collected is later on drained to the boiler through the holes which are made at the ends of the pipe.

SOLVED PROBLEMS

Problem 1

During a test carried to measure the dryness fraction of steam by separating calorimeter, the following observations were noted.

Solution

The mass of water separated = 0.85 kg/min.

The mass of steam passed out as recorded by measuring gauge = 10 kg/min.
Determine the dryness fraction of steam supplied.
since we have.

Dryness fraction of steam $x = \frac{m_s}{m_s + m_w}$

$$= \frac{10}{10 + 0.85}$$

Problem 2

In a throttling calorimeter, the pressure before and after the throttling are 14 bar and 1 bar respestively.

(a) Determine the dryness fraction of steam before passing through the throttling calorimeter, if the temperature after the throttling is 120°C.

(b) What is the value of the dryness fraction can be determined for same pressures before and after throttling.

Take Cp for steam to be 2.1 kJ/kgk.

Solution

Given that

(a) pressure before the throttling is 14 bar (state 1), pressure and temperature after throttling are 1 bar 120°C (state 2).

State (1) from steam table.

$$h_{f_1} = 830.0 \text{ kJ/kg}$$

$$h_{fg_1} = 1957.7 \text{ kJ/kg}$$

state (2) from steam table.

$$hg_2 = 2675.5 \text{ kJ/kg}$$

$$h_{f_1} + xh_{fg_1} = h_{g_2} + C_{ps}(T_2 - T_{sat})$$

$$830.0 + x \times 1957.7 = 2675.5 + 2.1\ (140 - 99.6)$$

$$x = 0.986$$

(b) Minimum dryness fraction that can be determined exist when no super heating takes place.

$$h_f + x'hg_1 = hg_2$$

$$830.0 + x' \times 1957.7 = 2675.5$$

$$x' = 0.9426$$

Problem 3

In a test with a separating and throttling calorimeter the following observations were made.

The absolute presure of steam, before throttling 8 bar.

The pressure and temperature of steam after throttling are 754 mm of Hg absolute and 120°C.

1.5 kg of water is trapped at the separator.

10.5 kg of condensed water is collected from the condenser.

Determine the dryness fraction of steam in the main take Cp for steam to be 2.1 kJ/kg k and barometric reading to be 750 mm of Hg.

Solution

The dryness fraction measured by separating calorimeter is

$$x_1 = \frac{m_s}{m_s + m_w} = \frac{10.5}{10.5 + 1.5} = 0.875$$

Absolute pressure after throttling = 754 mm of Hg.

$$= 754 \times 10^{-3} \times 9.8 \times 13.6 \times 10^3$$

$$= 1.005 \text{ bar.}$$

for throttling calorimeter.

$$h_{f_1} + x_2 h_{g_2} + C_{ps}(T_2 - T_{sat})$$

$$721.11 + x_2\,(2048.0) = 2675.68 + 2.1\,(120 - 99.64)$$

$$x_2 = 0.975$$

$\therefore$ Drynes fraction of steam in the main $x = x_1 \cdot x_2$

$$x = 0.875 \times 0.975 = 0.853$$

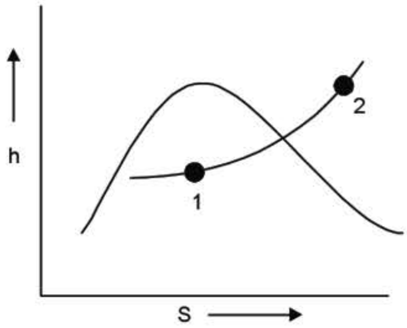
Problem 4

1.0 kg of wet steam of quality 0.7 at 0.3 MPa. pressure is heated at constant pressure till the temperature rises to 300°C, calculate the amount of energy added to heat.

Solution: At point 1

$$x = 0.7$$

$$p_1 = 0.3 \text{ MPa}$$



from steam table.

$$hf = 561.47 \text{ kJ/kg.}$$

$$h_{fg} = 2163.8 \text{ kJ/kg.}$$

$$h_1 = 561.47 + 0.7$$

$$h_1 = 2163.8 \text{ kJ/kg.}$$

h_2 at 0.3 MPa and 300°C from steam tables = 3069.3 kJ/kg.

$$h_2 = 3060 \text{ kJ/kg}$$

Heat added = $h_2 - h_1$ = 3069.3 – 2076.13 = 993.17 kJ/kg

EXERCISE

1. Differentiate between
   (a) Wet steam and superheated steam.
   (b) Throttling and isentropic expansion.
   (c) Fire tube and water tube boilers.
2. Explain the working of.
   (a) Separating calorimeter.
   (b) Throttling calorimeter.
   (c) Separating and throttling calorimeter
   (d) Cochran boiler.
   (e) Babcock and Wilcox boiler.
3. What do you mean by quatity of steam.
4. (a) What is a steam generator? Draw a neat sketch of a steam, generator and label its various parts.
   (b) Explain function of the following.

(1) Feed check value
(2) Fusible plug
(3) Economiser
(4) Superheater

5. What do you understand by mountings? Explain the function of all mountings used in boilers.
6. What do you understand by accessories? Explain all accessories used in boiler.

OBJECTIVE TYPE QUESTIONS

1. Heating of dry steam above saturation temperature is known as
   (a) enthalpy
   (b) superheating
   (c) super saturation
   (d) latent heat
2. Superheating of steam is done at
   (a) Constant volume
   (b) Constant temperature
   (c) Constant pressure
   (d) Constant entropy
3. The saturation temperature of steam with increase in pressure increases
   (a) linearly
   (b) rapidly first and than slowly
   (c) slowly first and then rapidly
   (d) inversely
4. One kg of steam sample contains 0.8 kg dry steam; its dryness fraction is
   (a) 0.2
   (b) 0.8
   (c) 1.0
   (d) 0.6
5. If x_1 and x_2 be the dryness fractions obtained in separating calorimeter of the steam will be.
   (a) $x_1 x_2$
   (b) $x_1 + x_2$
   (c) $\frac{x_1 + x_2}{2}$
   (d) $x_1 - x_2$
6. If a steam sample is nearly dry condition, then its dryness fraction can be most accurately determined by
   (a) throttling calorimeter
   (b) separating calorimeter
   (c) combined separating and throttling calorimeter
   (d) none of the above

7. A wet vapour can be completely specified by
   (a) temperature only
   (b) dryness fraction only
   (c) pressure only
   (d) pressure and dryness fraction only
8. On a Mollier chart, the constant pressure lines
   (a) diverge from left to right
   (b) diverge from right to left
   (c) are equally spaced throughout
   (d) first rise up and than fall
9. If x is the weight of dry steam and y is the weight of water in suspension then dryness fraction is equal to
   (a) $\frac{x}{x+y}$
   (b) $\frac{y}{x+y}$
   (c) $\frac{x}{x-y}$
   (d) $\frac{y}{x-y}$
10. Fire tube boiler are those in which
   (a) flue gases pass through tubes and water around it.
   (b) water passes through the tubes and flue gases around it.
   (c) forced circulation takes place
   (d) tubes are laid vertically
11. Which of the following is a fire tube boiler
   (a) locomotive boiler
   (b) Babcock and Wilcox boiler
   (c) Stirling boiler
   (d) all of the above
12. Which of the following is a water tube boiler
   (a) Locomotive boiler
   (b) Cochran boiler
   (c) Cornish boiler
   (d) Babcock and Wilcox boiler
13. One kg steam sample contains 0.4 kg water vapour. Its dryness fraction is
   (a) 0.4
   (b) 0.6
   (c) 0.4/1.5
   (d) 0.4×0.6

14. The water tubes in a Babcock and Wilcox boiler are
    (a) horizontal
    (b) vertical
    (c) inclined
    (d) horizontal and inclined
15. Which of the following boilers is best suited to meet fluctuating demands
    (a) Babcock and Wilcox
    (b) locomotive
    (c) Lancashire
    (d) Cochran
16. A fusible plug is fitted in small boilers in order to
    (a) avoid excessive built-up of pressure
    (b) avoid explosion
    (c) extinguish fire if the water level in the boiler falls below alarming level.
    (d) Control steam dome
17. The high pressure boiler is one producing steam at a pressure more than
    (a) atmospheric pressure
    (b) 5 kg/cm^2
    (c) 75–80 kg/cm^2
    (d) 40 kg cm^2
18. One kilowatt-hour energy is equivalent to
    (a) 1000 J
    (b) 250 kJ
    (c) 3600 kJ
    (d) 3600 kW/sec
19. The basic purpose of drum in a boiler is to
    (a) serve as storage of steam
    (b) serve as storage of feed water
    (c) remove salts from water
    (d) separate steam from water
20. A safety valve in a locomotive starts leaking. The leaking medium will be
    (a) water
    (b) dry steam
    (c) wet steam
    (d) superheated steam
21. Fusible plug for boiler is made of fusible metal containing tin, lead and
    (a) Bismath
    (b) copper
    (c) aluminium
    (d) nickel
22. The Conomiser is used in boilers to
    (a) Increase thermal efficiency of boiler
    (b) Conomise on fuel.

(c) increase flue gas temperature
(d) to heat feed water by bled steam

23. An economiser in a boiler
    (a) increases steam pressure
    (b) increases steam flow
    (c) decreases flue consumption
    (d) decreases steam pressure
24. The blow down cock in boiler is used for
    (a) regulating drum level by blowing unwanted water
    (b) emptying the boiler in case of shut down
    (c) To remove sludge or sediments from drum.
    (d) none of the above
25. Formation of scale on a boiler tube
    (a) protects it
    (b) increases its life
    (c) decreases its life
    (d) life is unaffected

ANSWERS

1. b	2. c	3. b	4. b	5. a
6. a	7. d	8. a	9. a	10. a
11. a	12. d	13. a	14. c	15. b
16. c	17. c	18. c	19. d	20. d
21. a	22. a	23. c	24. c	25. c