UNIT- 4
Thermodynamics

First law of thermodynamics- [RGPV June 08,09,11April 2009 Dec 08, 11]

First law of thermodynamics

"When a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surroundings is equal to net work done by the system on its surroundings.

$$\oint dQ = \oint dW$$

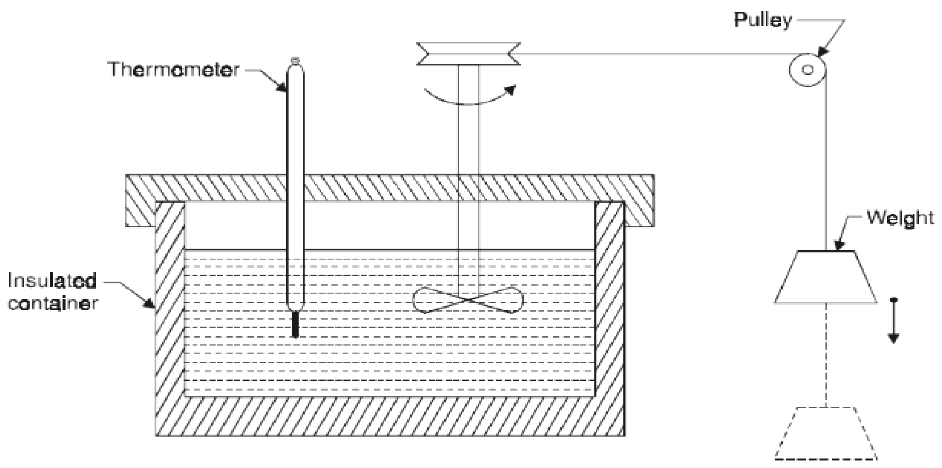
The first law of Thermodynamics cannot be proved analytically, but experimental evidence has repeatedly confirmed its validity, and since no phenomenon has been shown to contradict it, the first law is accepted as a law of nature. It may be remarked that no restriction was imposed which limited the application of first law to reversible energy transformation. Hence the first law applies to reversible as well as irreversible transformations: For non-cyclic process, a more general formulation of first law of thermodynamics is required. A new concept which involves a term called internal energy fulfills this need.

The First Law of Thermodynamics may also be stated as follows :

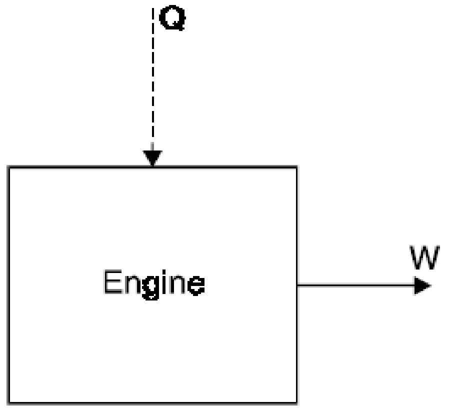
"Heat and work are mutually convertible but since energy can neither be created nor destroyed, the total energy associated with an energy conversion remains constant".

Or

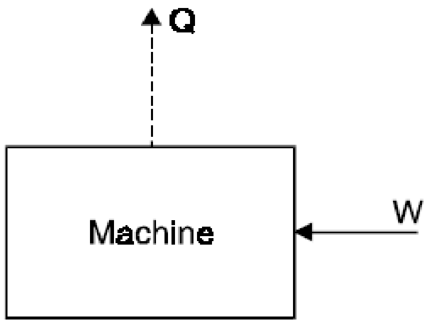
"No machine can produce energy without corresponding expenditure of energy, *i.e.*, it is impossible to construct a perpetual motion machine of first kind".



The work input to the paddle wheel is measured by the fall of weight, while the corresponding temperature rise of liquid in the insulated container is measured by the thermometer. It is already known to us from experiments on heat transfer that temperature rise can also be produced by heat transfer. The experiments show: (*i*) A definite quantity of work is always required to accomplish the same temperature rise obtained with a unit amount of heat. (*ii*) Regardless of returned by heat transfer in opposite direction to the identical state from which it started. The above results lead to the inference that *work and heat* are different forms of something more.



A PPM 1.



The converse of PMM 1.

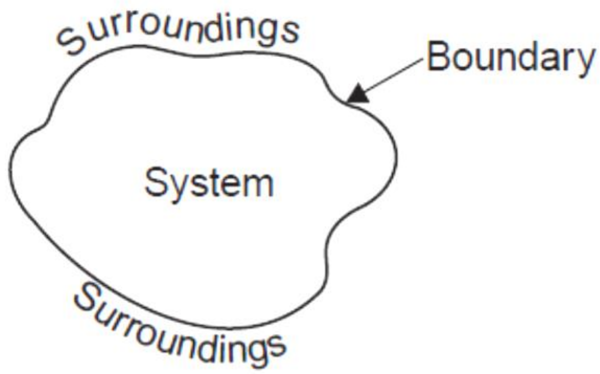
Definition of thermodynamics [RGPV.........]

Thermodynamics may be defined as follows:

Thermodynamics is an axiomatic science which deals with the relations among heat, work and properties of system which are in equilibrium. It describes state and changes in state of physical systems.
Or
Thermodynamics is the science of the regularities governing processes of energy conversion.
Or
Thermodynamics is the science that deals with the interaction between energy and material systems.

THERMODYNAMIC SYSTEMS

System, Boundary and Surroundings
System. A system is a finite quantity of matter or a prescribed region of space



Boundary. The actual or hypothetical envelope enclosing the system is the boundary of the system. The boundary may be fixed or it may move, as and when a system containing a gas is compressed or expanded. The boundary may be real or imaginary. It is not difficult to envisage a real boundary but an example of imaginary boundary would be one drawn around a system consisting of the fresh mixture about to enter the cylinder of an I.C. engine together with the remnants of the last cylinder charge after the exhaust process

Closed System

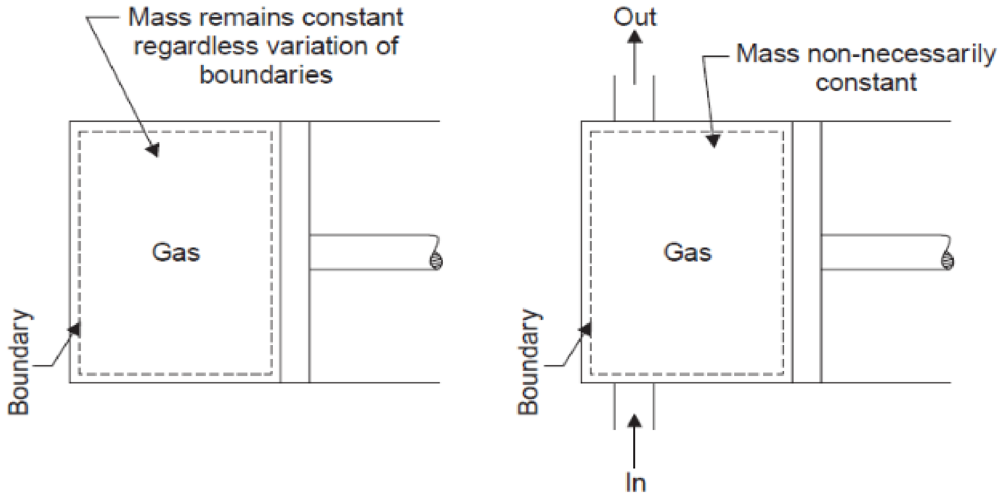
If the boundary of the system is impervious to the flow of matter, it is called a closed system. An example of this system is mass of gas or vapour contained in an engine cylinder, the boundary of which is drawn by the cylinder walls, the cylinder head and piston crown. Here the boundary is continuous and no matter may enter or leave.

Open System

An open system is one in which matter flows into or out of the system. Most of the engineering systems are open.

Adiabatic System

An adiabatic system is one which is thermally insulated from its surroundings. It can, however, exchange work with its surroundings. If it does not, it becomes an isolated system.



THERMODYNAMIC EQUILIBRIUM

A system is in thermodynamic equilibrium if the temperature and pressure at all points are same; there should be no velocity gradient; the chemical equilibrium is also necessary. Systems under temperature and pressure equilibrium but not under chemical equilibrium are
Sometimes said to be in metastable equilibrium conditions. It is only under thermodynamic equilibrium conditions that the properties of a system can be fixed.

Thus for attaining a state of thermodynamic equilibrium the following three types of equilibrium states must be achieved:

1. Thermal equilibrium. The temperature of the system does not change with time and has same value at all points of the system.

2. Mechanical equilibrium. There are no unbalanced forces within the system or between the surroundings. The pressure in the system is same at all points and does not change with
Respect to time.

3. Chemical equilibrium. No chemical reaction takes place in the system and the chemical composition which is same throughout the system does not vary with time.

Properties of systems

Property of a system is a characteristic of the system which depends upon its state, but not upon how the state is reached. There are two sorts of property:
1. Intensive properties. These properties do not depend on the mass of the system.
Examples: Temperature and pressure.

2. Extensive properties. These properties depend on the mass of the system.
Example:
Volume. Extensive properties are often divided by mass associated with them to obtain the intensive properties. For example, if the volume of a system of mass m is V, then the specific volume of matter within the system is V/ m = v which is an intensive property.

STATE

State is the condition of the system at an instant of time as described or measured by its properties. Or each unique condition of a system is called a state.

PROCESS

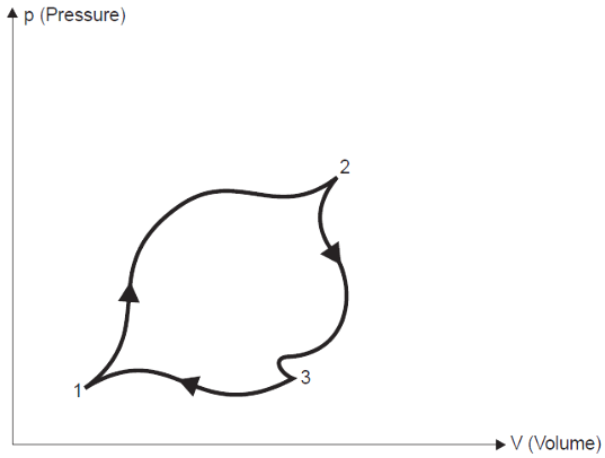
A process occurs when the system undergoes a change in a state or an energy transfer at a steady state. A process may be non-flow in which a fixed mass within the defined boundary is undergoing a change of state. Example: A substance which is being heated in a closed cylinder undergoes a non-flow process. Closed systems undergo non-flow processes. A process may be a flow process in which mass is entering and leaving through the boundary of an open system. In a steady flow process mass is crossing the boundary from surroundings at entry, and an equal mass is crossing the boundary at the exit so that the total mass of the system remains constant. In an open system it is necessary to take account of the work delivered from the surroundings to the system at entry to cause the mass to enter, and also of the work delivered from the system at surroundings to cause the mass to leave, as well as any heat or work crossing the boundary of the system.

Quasi-static process.

Quasi means ‘almost’. A quasi-static process is also called a reversible process. This process is a succession of equilibrium states and infinite slowness is its characteristic feature.

CYCLE

Any process or series of processes whose end states are identical is termed a cycle. The processes through which the system has passed can be shown on a state diagram, but a complete section of the path requires in addition a statement of the heat and work crossing the boundary of the system. Fig. 2.6 shows such a cycle in which a system commencing at condition '1' changes in pressure and volume through a path 123 and returns to its initial condition '1'.



POINT FUNCTION\

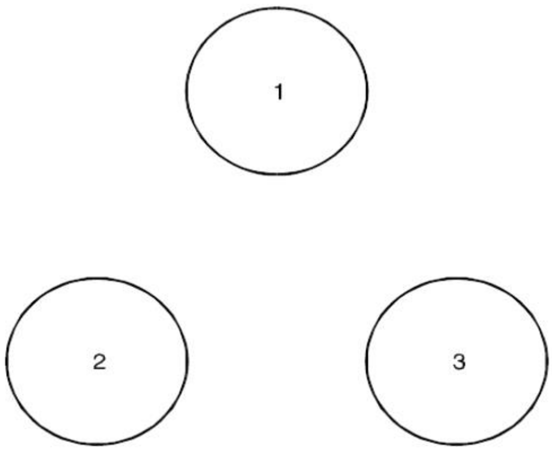
When two properties locate a point on the graph (co-ordinate axes) then those properties are called as point function. Examples. Pressure, temperature, volume etc.

PATH FUNCTION

There are certain quantities which cannot be located on a graph by a point but are given by the area or so, on that graph. In that case, the area on the graph, pertaining to the particular process, is a function of the path of the process. Such quantities are called path functions.
Examples. Heat, work etc.

ZEROTH LAW OF THERMODYNAMICS

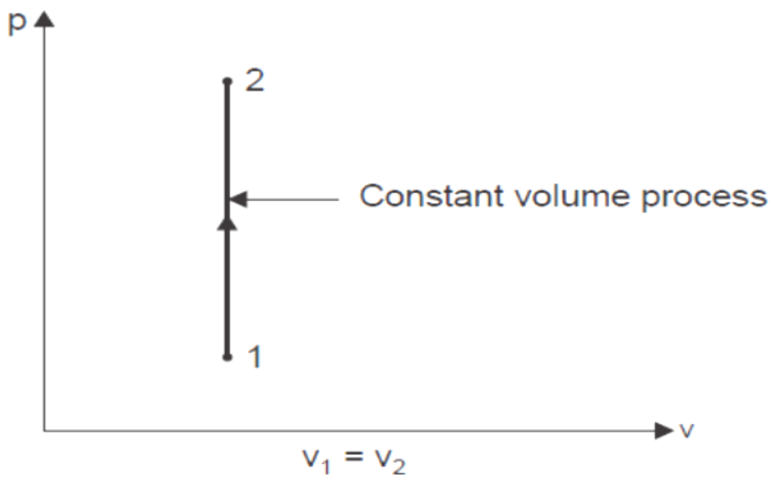
'Zeroth law of thermodynamics' states that if two systems are each equal in temperature to a third, they are equal in temperature to each other.



Example. Refer Fig. 2.7. System ‘1’ may consist of a mass of gas enclosed in a rigid vessel fitted with a pressure gauge. If there is no change of pressure when this system is brought into contact with system ‘2’ a block of iron, then the two systems are equal in temperature (assuming that the systems 1 and 2 do not react each other chemically or electrically). Experiment reveals that if system ‘1’ is brought into contact with a third system ‘3’ again with no change of properties then systems ‘2’ and ‘3’ will show no change in their properties when brought into contact provided they do not react with each other chemically or electrically. Therefore, ‘2’ and ‘3’ must be in equilibrium.

This law was enunciated by R.H. Fowler in the year 1931. However, since the first and second laws already existed at that time, it was designated as zeroth law so that it precedes the first and second laws to form a logical sequence.

APPLICATION OF FIRST LAW OF THERMODYNAMICS TO NON-FLOW OR CLOSED SYSTEM



In a constant volume process the working substance is contained in a rigid vessel, hence the boundaries of the system are immovable and no work can be done on or by the system, other than paddle-wheel work input. It will be assumed that '*constant volume*' implies zero work unless stated otherwise.

Considering mass of the working substance *unity* and applying first law of thermodynamics
to the process

$$Q = (u_2 - u_1) + W$$

The work done $W = \int_1^2 p\,dv = 0$ as $dv = 0$.

$\therefore$ $$Q = (u_2 - u_1) = c_v(T_2 - T_1)$$

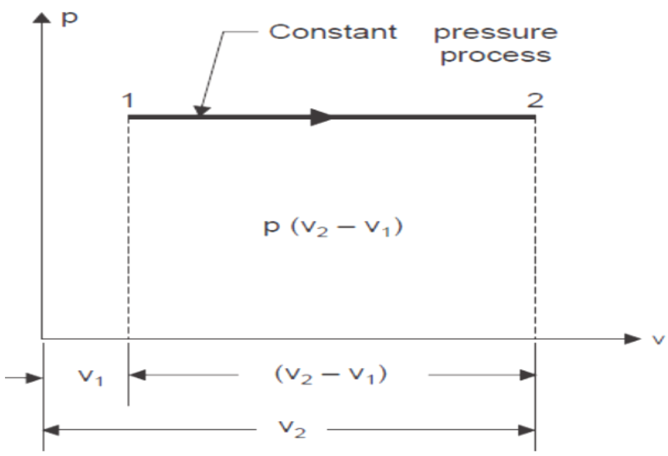
where c_v = Specific heat at constant volume.

For mass, m, of working substance

$$Q = U_2 - U_1 = mc_v(T_2 - T_1)$$

2. Reversible Constant Pressure (or Isobaric) Process (*p* = constant).

It can be seen from Fig. that when the boundary of the system is inflexible as in a constant volume process, then the pressure rises when heat is supplied. Hence for a constant
pressure process, the boundary must move against an external resistance as heat is supplied ; for instance a gas in a cylinder behind a piston can be made to undergo a constant pressure process. Since the piston is pushed through a certain distance by the force exerted by the gas, then the work is done by the gas on its surroundings. Fig. shows the system and states before and after the heat addition at constant pressure.



$$Q = (u_2 - u_1) + W$$

The work done, $W = \int_1^2 p dv = p(v_2 - v_1)$

$\therefore$ $Q = (u_2 - u_1) + p(v_2 - v_1) = u_2 - u_1 + pv_2 - pv_1$

$$= (u_2 + pv_2) - (u_1 + pv_1) = h_2 - h_1$$

or $Q = h_2 - h_1 = c_p (T_2 - T_1)$

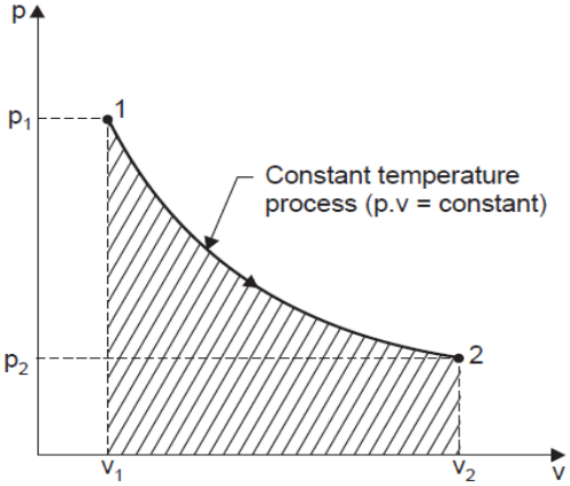
where h = Enthalpy (specific), and

c_p = Specific heat at constant pressure.

For mass, m, of working substance

$$Q = H_2 - H_1 = mc_p (T_2 - T_1)$$

3. Reversible Temperature (or Isothermal) Process (*pv* = constant, *T* = constant):



The constant C can either be written as p_1v_1 or as p_2v_2, since

$$p_1v_1 = p_2v_2 = \text{constant, } C$$

$$W = p_1v_1 \log_e \frac{v_2}{v_1} \text{ per unit mass of working substance}$$

$$W = p_2v_2 \log_e \frac{v_2}{v_1} \text{ per unit mass of working substance}$$

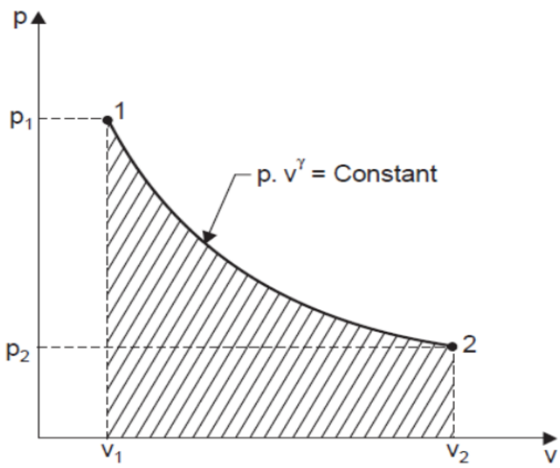
$$\therefore \quad Q = W = p_1v_1 \log_e \frac{v_2}{v_1}$$

For mass, m, of the working substance

$$Q = p_1V_1 \log_e \frac{V_2}{V_1}$$

$$Q = p_1V_1 \log_e \frac{p_1}{p_2} \qquad \left[\because \frac{V_2}{V_1} = \frac{p_1}{p_2}\right]$$

Reversible Adiabatic Process:



The work done is given by the shaded area, and this area can be evaluated by integration.

$$W = \int_{v_1}^{v_2} p\,dv$$

Therefore, since pv^{γ} = constant, C, then

$$W = \int_{v_1}^{v_2} C\frac{dv}{v^{\gamma}} \qquad \left[\because\ p = \frac{C}{v^{\gamma}}\right]$$

$$W = C\int_{v_1}^{v_2}\frac{dv}{v^{\gamma}} = C\left|\frac{v^{-\gamma+1}}{-\gamma+1}\right|_{v_1}^{v_2}$$

$$= C\left(\frac{v_2^{-\gamma+1} - v_1^{-\gamma+1}}{1-\gamma}\right) = C\left(\frac{v_1^{-\gamma+1} - v_2^{-\gamma+1}}{\gamma-1}\right)$$

The constant in this equation can be written as $p_1 v_1^{\gamma}$ or as $p_2 v_2^{\gamma}$. Hence,

$$W = \frac{p_1 v_1^{\gamma} v_1^{-\gamma+1} - p_2 v_2^{\gamma} v_2^{-\gamma+1}}{\gamma-1} = \frac{p_1 v_1 - p_2 v_2}{\gamma-1}$$

$$W = \frac{p_1 v_1 - p_2 v_2}{\gamma-1}$$

$$W = \frac{R(T_1 - T_2)}{\gamma-1}$$

Relationship between T and v, and T and p :

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{\gamma}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Solve Problems:

Question 1 A stationary mass of gas is compressed without friction from an initial state of $0.3m^3$ and 0.105 MPa, to a final state of $0.15m^3$ and 0.105MPa, during the compression process the pressure remaining constant. If there is a transfer of 37.6 KJ of heat from the gas during the process, determine change in the internal energy of the gas?

Solution:

$Q = \Delta U + W$

Or $Q_{1-2} = U_2 - U_1 + W_{1-2}$

Since only expansion work is involved hence $W_{1-2} =$ pdV

$W_{1-2} =$ pdV $= p(V_2 - V_1)$

$= 0.105(0.15 - 0.30)$ MJ

$= -15.75$ KJ [- ve sign indicates work is done on the system]

$Q_{1-2} = -37.6$kJ

Substituting the values of in the following equation

$Q = \Delta U + W$

-37.6 KJ $= \Delta U - 15.75$KJ

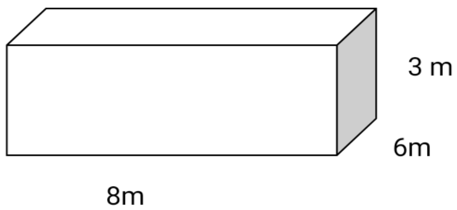
Therefore $\Delta U = U_2 - U_1 = -21.85$KJ Answer

-ve sign indicates that internal energy of the gas decreases by 21.85 KJ in the process.

Question 2 Twenty people attended a party in a small room of size 6m by 8 m & have a 3m ceiling. Assuming that each person gives up about 400KJ of heat per hour and the room is completely sealed off & insulated. Calculate the air temperature rise occurring within 15 minutes. Assume C_v of air 0.718 KJ/kg and R = 0.278 KJ/kgK , each person occupies a volume of 0.07m^3 and the initial temperature of air as 20°C. Give your comment on the result?

Solution:

Refer to the following figure



Consider the room as thermodynamic system and assume that the people are adding heat energy to the air in a room, as the process is taking place at constant volume. W=0

Volume of room is $V_{room} = 8 \times 6 \times 3 = 144 m^3$

The volume of air is obtained by subtracting the volume occupied by the people.

$V_{air} = 144 - 0.07 \times 20 = 142.6 m^3$

Assuming the standard atmospheric conditions of 1.103bar, the mass of air is

$m = pV/RT = (1.013\times10^5\times142.6)/(287\times293) = 171.78$Kg

The amount of heat released in one hour =400×20=8000KJ/h.

In 15 minutes the amount of heat released to the room =Q=8000KJ/h ×15/60

=2000KJ

From first law, $Q-W = \Delta U$ [W=0]

$\Delta U = m\,C_v\,\Delta T$

$\Delta T = 2000/(171.78\times0.718) = 16.31^{o}C$ Answer

The problem illustrates the importance of adequate ventilation when a large number of people are occupying a small room. It can be seen from the calculation that the temperature rise is approx. 16°C.

Question 3 A tank containing hot fluid is stirred by a paddle wheel doing 100 kJ of work on the fluid. At the same time the fluid looses 500 kJ of heat energy. If the initial internal energy of the fluid is 800 kJ, determine the final internal energy. Neglect the energy stored in the paddle wheel.

Solution:

Consider the contents of the tank as the system. This is the closed system since no mass crosses the boundary during the process. We observe that the volume of the rigid tank is constant, and thus there is no boundary work and $V_2=V_1$. Also, heat is lost from the system and the shaft work is done on the system.

Assume $\Delta E=\Delta U$ neglecting other forms of energy like PE and KE during the process.
Applying the energy balance on the system gives $E_{in}-E_{out}=E_{system}$

Q=-500 kJ

$Q=\Delta U + W$ [W= W stirrer = -100 kJ]

$-500 = \Delta U+(-100)$

$\Delta U=U_2 - U_1 = -400 = U_2 - 800$

U_2 =400KJ Answer

Therefore, the final internal energy of the system is 400KJ.

Question 4 An insulated tank contains a gas, a paddle wheel connected to shaft and a resister connected to a battery. A current of 8 ampere is supplied to the resister while maintaining a potential difference of 10 volt and at the same time if a paddle wheel is connected to a shaft producing a torque of 10 Nm at a speed of 600 rpm. Calculate the net power and the net work on the system, if the paddle work and heating continues for 1 minute. Also sketch the system.

Solution: Refer the following figure. The system is the gas contained inside the tank within the system boundary.

Given:

Torque = T=10Nm

speed of the shaft = N= 600 rpm

Potential difference =V=10 Volts

Current supplied = I = 8 amp.

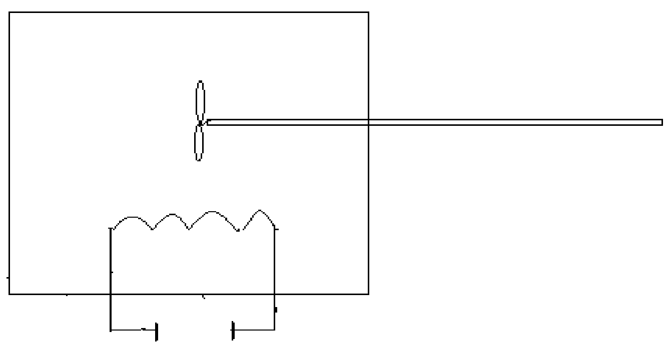
Power of paddle = P_{paddle} = 2πnT

=2π×(600/60)×10 = 628.57W

Power of the resister = P_{elec} =VI = 10×8 = 80 W

Total power = P_{net} = P_{paddle} + P_{elec}= 708.57 W

Work done on the system = P_{net} ×time= 708.57×60=42514.28 J= 42.5 kJ Answer



Question 5. The properties of a closed system change following the relation between pressure and volume as pV = 3.0 where p is in bar V is in m3. Calculate the work done when thepressure increases from 1.5 bar to 7.5 bar. Solution. Initial pressure, p1 = 1.5 bar

Final pressure, p2 = 7.5 bar
Relation between p and V, pV = 3.0
Work done = ?

The work done during the process is given by

$$W = \int_{V_1}^{V_2} p\,dV$$

$$V_1 = \frac{3.0}{p_1} = \frac{3.0}{1.5} = 2\ \text{m}^3$$

$$V_2 = \frac{3.0}{p_2} = \frac{3.0}{7.5} = 0.4\ \text{m}^3$$

$$\therefore \quad W = 10^5 \int_{2}^{0.4} \frac{3.0}{V}\,dV\ \text{Nm} \qquad [\because\ 1\ \text{bar} = 10^5\ \text{N/m}^2]$$

$$= 10^5 \times 3.0\ [\log_e V]_2^{0.4} = 10^5 \times 3.0(\log_e 0.4 - \log_e 2)$$

$$= -3 \times 10^5 \log_e (2/0.4) = -3 \times 10^5 \times \log_e 5 = -3 \times 10^5 \times 1.61\ \text{Nm}$$

$$= -4.83. \times 10^5\ \text{Nm} = -4.83 \times 10^5\ \text{J} = -\mathbf{483\ kJ.}\quad \textbf{(Ans.)}$$

Question 6. To a closed system 150 kJ of work is supplied. If the initial volume is 0.6 m3 and pressure of the system changes as p = 8 – 4V, where p is in bar and V is in m3, determine the final volume and pressure of the system.

Solution. Amount of work supplied to a closed system = 150 kJ
Initial volume = 0.6 m3
Pressure-volume relationship, p = 8 – 4V
The work done during the process is given by

Solution. Amount of work supplied to a closed system = 150 kJ

Initial volume = 0.6 m^3

Pressure-volume relationship, $p = 8 - 4V$

The work done during the process is given by

$$W = \int_{V_1}^{V_2} pdV$$

$$= 10^5 \int_{0.6}^{V_2} (8 - 4V)dV = 10^5 \left[8V - 4 \times \frac{V^2}{2}\right]_{0.6}^{V}$$

$$= 10^5[8(V_2 - 0.6) - 2(V_2^2 - 0.6^2)]$$

$$= 10^5[8V_2 - 4.8 - 2V_2^2 + 0.72]$$

$$= 10^5[8V_2 - 2V_2^2 - 4.08] \text{ Nm or J}$$

But this work is equal to -150×10^3 J as this work is supplied to the system.

$\therefore$ $-150 \times 10^3 = 10^5[8V_2 - 2V_2^2 - 4.08]$

or $2V_2^2 - 8V_2 + 2.58 = 0$

$$V_2 = \frac{8 \pm \sqrt{64 - 4 \times 2 \times 2.58}}{4} = \frac{8 \pm 6.585}{4} = 0.354 \text{ m}^3$$

Positive sign is incompatible with the present problem, therefore it is not considered.

$\therefore$ **Final volume, V_2 = 0.354 m^3. (Ans.)**

and, **final pressure, p_2** $= 8 - 4V = 8 - 4 \times 0.354$

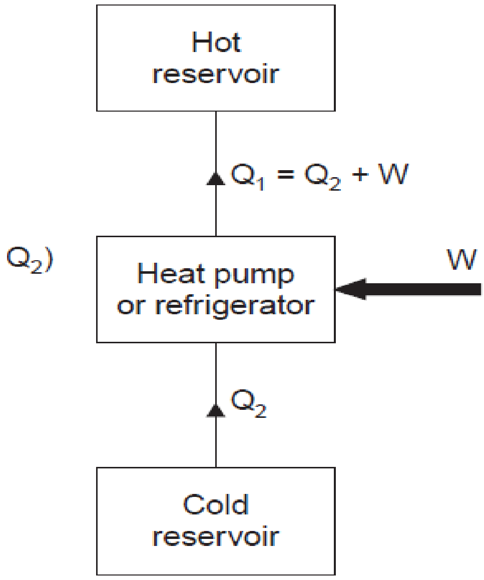
$= 6.584$ bar $=$ **6.584×10^5 N/m² or Pa. (Ans.)**

Second law of thermodynamics[RGPV June08, 10, 11 April 09, 10 Sept. 09]

Second law of thermodynamics
clausius Statement

"It is impossible for a self acting machine working in a cyclic process unaided by any external agency, to convey heat from a body at a lower temperature to a body at a higher temperature."

In other words, heat of, itself, cannot flow from a colder to a hotter body.



(b)
Heat pump or refrigerator

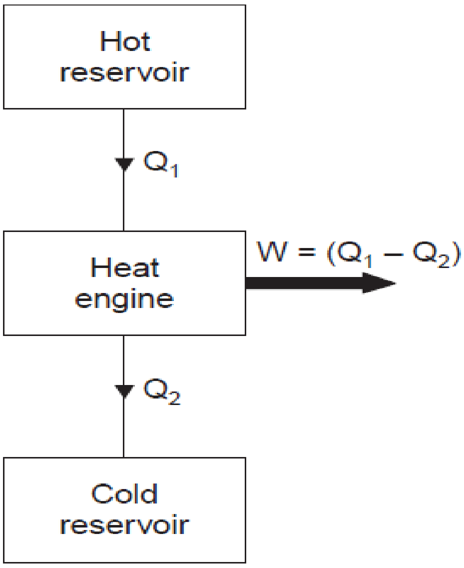
For a reversed heat engine above Fig. acting as a refrigerator when the purpose is to achieve the maximum heat transfer from the cold reservoir, the measure of success is called the co-efficient of performance (C.O.P.). It is defined by the ratio:

Co-efficient of Performance, (C.O.P.) ref. = Q/W

Where, Q2 = Heat transfer from cold reservoir, and
W = the net work transfer to the refrigerator.

Kelvin-Planck Statement

"It is impossible to construct an engine, which while operating in a cycle produces no other effect except to extract heat from a single reservoir and do equivalent amount of work". Although the Clausius and Kelvin-Planck statements appear to be different, they are really
equivalent in the sense that a violation of either statement implies violation of other.



(a)
Heat engine

A *heat engine* is used to produce the maximum work transfer from a given positive heat transfer. The measure of success is called the *thermal efficiency* of the engine and is defined by the ratio:

Thermal efficiency, $\eta_{th} = W/Q1$

Where, *W* = Net work transfer from the engine,

Q1 = Heat transfer to engine Steam Generator [RGPV June06, 08, 10, Dec.03, 04, 08 Feb.05,08]

A steam generator or boiler is usually a closed vessel made of steel. Its function is to transfer the heat produced by the combustion of fuel to water and ultimately to generate steam. Open vessels, generating steam at atmospheric pressure are not considered to be boiler

Classification of Boilers
[1] Relative position of hot gas and water

• Fire tube boiler
Hot gasses pass through the tubes that are surrounded by water. Horizontal return tubular, vertical tubular, Lancashire, Cochran, Cornish, locomotive fire box, scotch marine etc.

• Water tube boiler

The tubes contain water and the hot gases flow outside Babcock and Wilcox Stirling boiler La mont boiler

[2]Method of firing

• Internally fired boiler
Lancashire, Locomotive, and Scotch
• Externally fired boiler
Babcock and Wilcox

[3]Pressure of steam

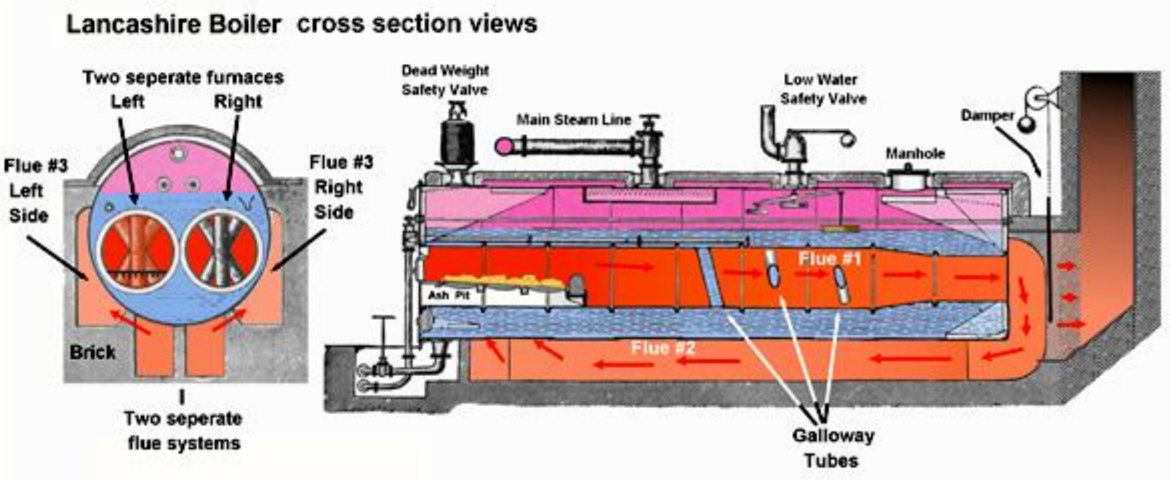
• High pressure (>80 kg/cm2)
Babcock and Wilcox Lamont etc
• Low pressure
(<80 kg/cm2) Cochran, Cornish, Lancashire and Locomotive

[4] Method of circulation of water
• Natural circulation
• Forced circulation

[5] Heat source
• Combustion of solid, liquid, or gas
• Electrical or nuclear energy
• Hot waste gases of other chemical reactions

Working principal of boiler:
Lancashire boiler

Theory
A Lancashire boiler is a double fire tube boiler, internally fired, horizontal, natural draught, and natural circulation type of boiler. This boiler is very popular and reliable because of simplicity of design and ease of operation. The boiler has good steaming quality, and coal of inferior quality can be used. it has low maintenance and operating cost. This boiler is widely used in sugar mills and chemical industries. This boiler is used where large reservoir of water and steam are required.



Its main features and brickwork setting is shown in the figure. Several rings of steel plates we are either welded or riveted to make the cylindrical shell of suitable dimensions. This boiler has two parallel flue pipes throughout the length of boiler. Both the flue tubes, which carry hot gases, lay below the water level. To accommodate a grate of sufficient area and minimum length, these flue tubes are larger in diameter at the front of the shell. to control the gas flow and to control the amount of air entering the grate, dampers are used which are placed in path of flue gases.

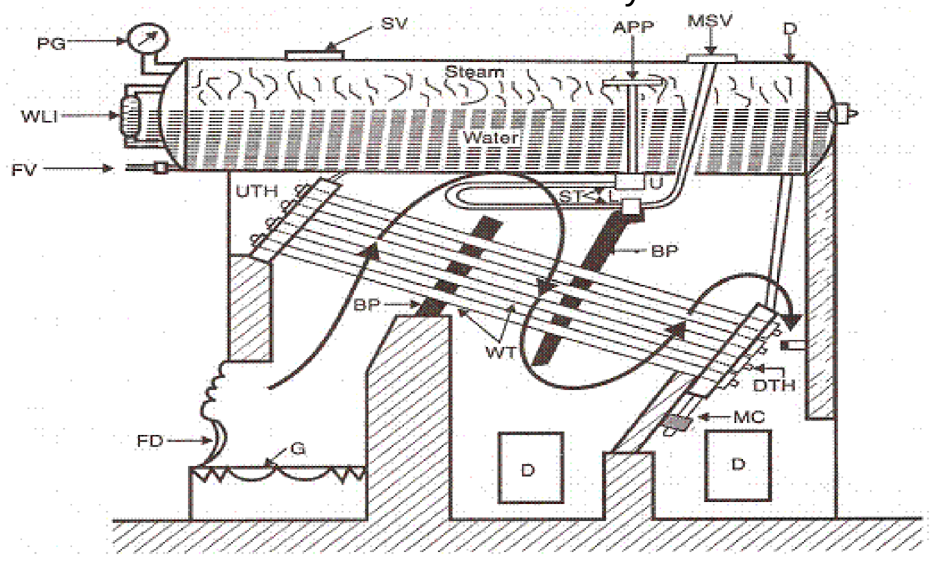
Coal is fed to the grates through fire doors. Each of the flue tubes has its own furnace with grates where its combustion takes place and the flue gases rising from the furnaces pass over the fire bridge and traverse along the horizontal path. the hot gases leaving the grate pass up to the back end of the tubes and then travel back from the bottom flue passage to the front of boiler, where the gases bifurcate and pass into the two side flues. Thereafter, the gases in the two side flues enter the common flue and finally discharged to the atmosphere through chimney.
Babcock & Wilcox boiler.

Theory

This is a horizontal, externally fired, water tube, natural circulation type stationary boiler. This boiler is the most common type used in thermal power plants for generation of steam in large quantities. It consists of a high pressure steel drum mounted at the top .from each end of the drum, connections are made with the uptake header and a down take header. The headers are joined to each other by a large number of water tubes which are kept inclined at an angle of about 15degree to the horizontal. The water tubes are straight, solid drawn steel tubes about 10 cm in diameter and are expanded into the bored holes of the headers.
The furnace is located below the uptake header. The coal is fed to the chain grate stoker through the fire door baffles are provided across the water tubes to act as

deflectors to the flue gases. The hot gases rise upwards, go down and then rise up again and finally escape to chimney through the smoke chamber. To maintain a uniform velocity of flue gases throughout their travel, the passage of the gases is decreased from furnace to exit.

The circulation of water is maintained by convective currents. The cold water flows from the drum to the rear header and thus cycle is repeated. For getting superheated steam, the steam accumulated in the steam space is sent to the superheated tubes which are arranged above the water tubes. the super heated steam is finally supplied through a steam stop valve and steam pipe. Evaporative capacity of such boiler rages from20, 000 to 40,000 kg/hour and operating pressures of 11.5 to 17.5 bar are quite common. the inspection of boiler can be carried out even when the boiler is in operation, draught loss is minimum and replacement of defectives tubes can be made readily.



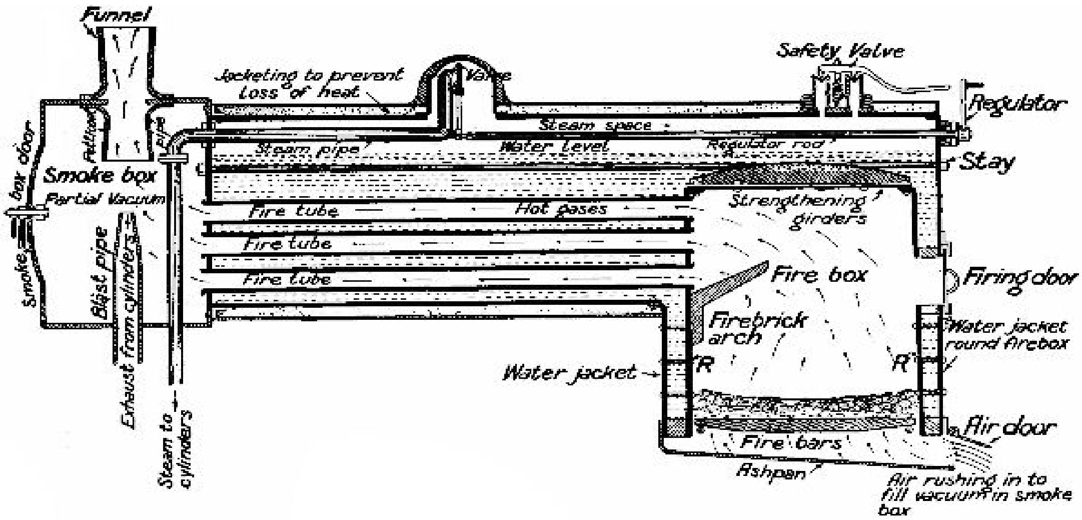
D = Drum
DTH = Down take header
WT = Water tubes
BP = Baffle plates
D = Doors
G = Grate
FD = Fire door
MC = Mud collector
WLI = Water level indicator
PG = Pressure gauge
ST = Superheater tubes
SV = Safety valve
MSV = Main stop valve
APP = Antipriming pipe
L = Lower junction box
U = Upper junction box
FV = Feed valve

Locomotive boiler

Theory

A fire-tube boiler is a type of boiler in which hot gases from a fire pass through one or more tubes running through a sealed container of water. The heat energy from the gases passes through the sides of the tubes by thermal conduction, heating the water and ultimately creating steam.

The fire-tube boiler developed as the second of the three major historical types of boilers: low-pressure tank or "haystack" this type of boiler was used on virtually all steam locomotives in the horizontal "locomotive" form. This has a cylindrical barrel containing the fire tubes, but also has an extension at one end to house the "firebox". This firebox has an open base to provide a large grate area and often extends beyond the cylindrical barrel to form a rectangular or tapered enclosure.
A fire-tube boiler is sometimes called a "smoke-tube boiler" or "shell boiler" or sometimes just "fire pipe".



A locomotive boiler is a fire tube, internally fixed, horizontally, multi tubular boiler. It is mainly employed in locomotives through it may also be used as a stationary boiler. The hot gasses which are generated due to burning of the coal are deflected by an arch of a fire bricks, so that walls of the fire box may be heated properly.
In the locomotive-type boiler, fuel is burnt in a firebox to produce hot combustion gases. The firebox is surrounded by a cooling jacket of water connected to the long, cylindrical boiler shell. The hot gases are directed along a series of fire tubes, or flues, that penetrate the boiler and heat the water thereby generating saturated ("wet") steam.
In the locomotive boiler, the saturated steam is very often passed into a super heater, back through the larger flues at the top of the boiler, to dry the steam and heat it to superheated steam.
Draught for fire tube boilers, particularly in marine applications, is usually provided by a tall partial vacuum. Modern industrial boilers use fans to provide forced or induced draughting of the boiler.
Locomotive-type boilers are also used in traction engines, steam rollers, portable engines and some other steam road vehicles. The inherent strength of the boiler means it is used as the basis for the vehicle: all the other components, including the wheels, are mounted on brackets attached to the boiler. it is rare to find super

heaters designed into this type of boiler, and they are generally much smaller (and simpler) than railway locomotive types.

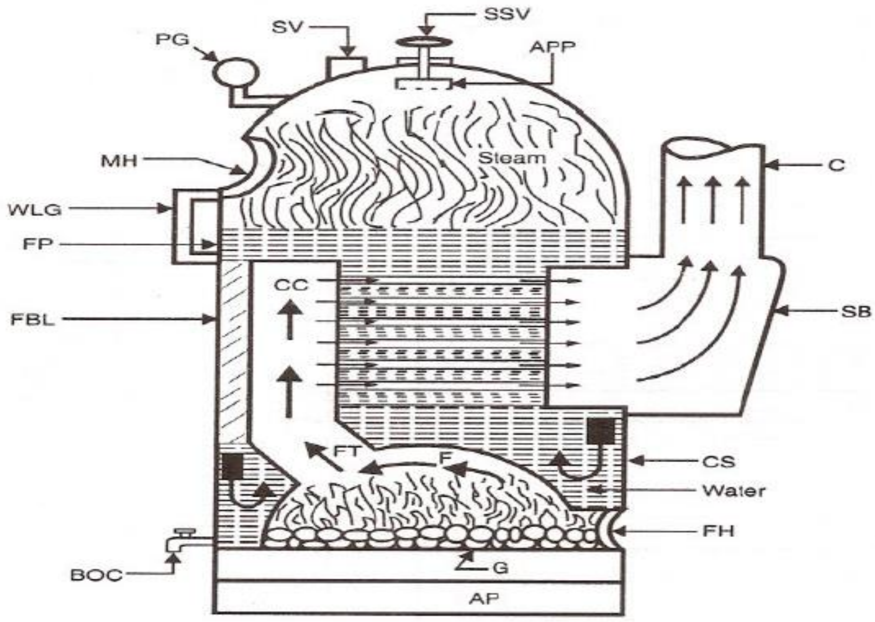
Cochran boiler

It is one of the best types of vertical multi-tubular boiler, and has a number of horizontal fire tubes it also a low pressure boiler.

Construction:

Cochran boiler consists of a cylindrical shell with a dome shaped top where the space is provided for steam. The furnace is one piece construction and is seamless. Its crown has a hemispherical shape and thus provides maximum volume of space.

Working: the fuel is burnt on the grate and ash is collected and disposed of from ash pit. The gases of combustion produced by burning of fuel enter the combustion chamber through the flue tube and strike against fire brick lining which directs them to pass through number of horizontal tubes, being surrounded by water. After which the gases escape to the atmosphere through smoke box and chimney.



CS = Cylindrical shell
CC = Combustion chamber
FBL = Fir brick lining
F = Furnace (dome shaped)
BOC = Blow off cock
SSV = Steam stop valve
APP = Antipriming pipe
PG = Pressure gauge

FT = Flue tube
SB = Smoke box
C = Chimney
FH = Fire hole
G = Grate
AP = Ash pit
SV = Safety valve
MH = Man hole
WLG = Water level gauge

Boilers mountings & accessories

Introduction
The boiler mountings are added on the boiler for its safe working. While accessories are added on the boiler to improve its performance.

Boiler mountings:-
The boiler mounting are the part of the boiler and are required for proper functioning. in accordance with the Indian boiler regulations of the boiler mounting is essential fittings for safe working of the boiler.

1. Safety valve: - 2 numbers.
2. Water level indicator: - 2 numbers.
3. Pressure gauge: - 1 numbers.
4. Steam stop valve:- 1numbers.
5. Feed check valve.
6. Blow off cock
7. Main hole.
8. Mud hole.
9. Fusible plug.
10. High pressure and low water safety valve on Lancashire and Cornish boiler.

SAFETY VALVE
Safety valves are located on the top the boiler. They guard the boiler against the excessive high pressure of steam inside the drum. If the pressure of the steam in the boiler drum exceed the working pressure, then the safety valve allow to blow off certain quantity of steam to atmosphere. Thus the pressure of steam in the drum falls. The escape of steam makes a audio noise to warn the boiler attendant.

There are 4 types of safety valve.
1. Dead weight safety valve.
2. Spring loaded safety valve.
3. Lever loaded safety valve.
4. High steam& low water safety valve.

Dead weight safety valve
It is very similar to dead weigh (whistle) loaded on pressure cooker& functions in similar way. A gun metal valve resets on gun metal seat. The gun metal seat is mounted on steel steam pipe. The valve is fastened to weight carrier. The total weights in the form of cylindrically disc are placed on the carrier. Therefore the total weight placed on the carrier is acting downward. This is the weight of cast iron

carrier & valve itself.

Spring loaded safety valve

The dead weight safety valve cannot be used on locomotive & marine boiler as the jerks, pitching, rolling may change the load on the valve & it can open frequently under working pressures. The spring loaded safety valve is used on locomotive, marine and high pressure boiler.

Lever loaded safety valve

The body of the valve is fattened on the top of the boiler shell. a gun metal is placed in steam passage formed in the casting. A cast iron lever attached to a fulcrum on one end & loaded by weight on other end keeps the valve on sheets in closed position.

Water level indicator

Water level indicator is located in front of boiler in such a position that the level of water can easily be seen by attendant. Two water level indicators are used on all boilers. a water level consists of a metal tube& a strong glass tube with marking. The upper & lower ends of these tubes are connected to two gun metal hollow pipes.

Fusible plug

It is very important safety device, which protects the fire tube boiler against overheating. It is located just above the furnace in the boiler.. During the normal boiler operation, the fusible plug is covered by water& its temp. Does not rise to its melting state. but when the water level falls too low in the boiler, it uncovers the fusible plug. The furnace gases heat up the plug & fusible plug melts, the inner plug falls down.

Feed check valve

The feed check valve is fitted to the boiler, slightly below the working level in the boiler, it is used to supply high pressure feed water to boiler. It also prevents the returning of feed water from the boiler if feed pump fails to work. a feed check consists of two valves: feed valve& check valve.

Steam stop valve

The steam stop valve is located on the highest part of the steam space. It regulates the steam supply to use. The steam stop valve can be operated manually or automatically. A hand operated steam stop valve.

Boiler accessories

The accessories are mounted on the boiler to increase its efficiency. These units are optional on an efficient boiler. with addition of accessories on the boiler the plant accessories also increases. The following accessories used on a modern boiler.

1. Super heater
2. Economiser
3. Air preheated

Super heaterIt is heat exchanger in which heat of combustion products is used to dry the wet steam& to increase its temp. During superheating the steam, pressure remains constant, its temp & volume increase. basically a super heater consists of a set of small diameter four tubes in which steam flows & takes up the heat from the hot flue gases

Economiser

An economiser is a heat exchanger used for heating the feed water before it enter the boiler the economizer recovers some of waste heat of hot flue gases going to chimney. It helps in improving the boiler efficiency. it is placed in the path of flue gases at the near end of the boiler just before air preheater. The most popular economizer is greens economizer.

Air preheater

The function of an air preheater is similar to economizer. it recovers some portion of the waste heat of hot flue gases going to chimney & transfers same to the fresh air before it enter the combustion chamber. Due to preheating of air, the furnace temp. Increases. it results in rapid combusting of fuel with less soot, smoke& ash.

Comparison between Water Tube and Fire Tube Boilers & Boiler draught [RGPV June06, 08, 10, Dec.03, 07, 08 Feb.05,08]

Water Tube Boilers	Fire Tube Boilers
The water circulates inside the tubes which are surrounded by hot gases from the furnace	The hot gases from the furnace pass through the tubes which are surrounded by water in the shell
It is a high pressure boiler	It cannot handle high pressure
The rate of generation of steam is high	The rate of generation of steam is relatively low
Overall efficiency is up to 90%	Overall efficiency is up to 75%

It is preferred for widely fluctuating loads	It is not preferable for fluctuating loads for a longer time period
The operating cost is high	The operating cost is less
The bursting chances are higher but bursting doesn't produce any destruction to the whole boiler	The bursting chances are less but bursting produces greater risk to the damage of the property
is used for large power plants	It is generally used for supplying steam on a small scale and is not suitable for large power plants

Essential of a good boilers

1. The boiler should be capable of generating steam at the required pressure and of the required quality quickly and with minimum fuel Consumption.
2. The initial cost, installation cost and the maintenance cost of the boiler should not be too high.
3. The boiler should be light in weight, should need the least amount of brick work construction and should occupy small floor area.
4. The boiler should meet the fluctuating demands or steam supply without being overheated
5. The different parts of the boiler should be easily approachable for repairs.
6. There should be no deposition of mud and other foreign particles on the heated surfaces
7. The boiler should conform to the safety regulations as laid down in the "Boilers Act".

Boiler Draught:

The rate of steam generation in a boiler depends upon the rate at which the fuel is burnt, To burn the fuel rapidly, the continuous supply of fresh air through the grate is required which in turn discharges the products of combustion through the chimney to the atmosphere. Draught is a small pressure difference that causes the flow of air through the bed of fuel on the furnace grate to the chimney.

Object of draught

1. To supply sufficient air for the combustion of fuel.
2. To push out the hot flue gases from the combustion chamber of the boiler to move through the system.
3. To discharge the used (spent) flue gases to the atmosphere through chimney. of fuel burning is very high, artificial draught is provided. Artificial draught is usually produced by mechanical means such as fans, blower or steam jet. If the draught is produced by a fan, it is called mechanical draught or fan draught and if produced by steam jet it is referred to as steam jet draught. Steam jet draught is used in small installations and locomotives whereas the mechanical draught is preferred in power stations.

(A) Forced draught

In a forced draught system a fan or blower is installed near the base of the boiler or at the entrance of air-preheater. The air is forced to pass through the furnace, flue tubes, economiser, airpreheater, and to the chimney.

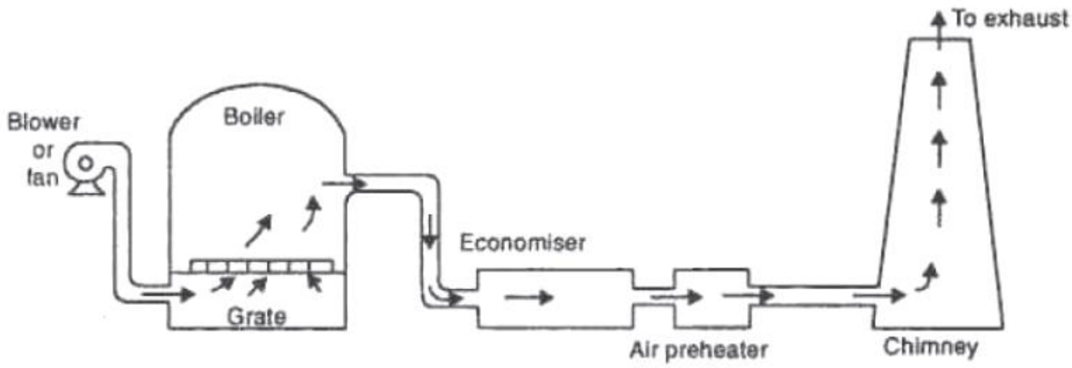


Figure: Forced fan draught

This draught system as shown in Fig. (&31) is known as positive draught system or forced draught system because the pressure of air throughout the system is above the atmospheric pressure and air is forced to flow through the system. Chimney used in this system is not for producing draught but just to dispose off the hot gases into the atmosphere.

(B) Induced draught

In the induced draught system a fan or blower is placed at the outlet of an economiser or air-preheater. In this draught system, the air pressure in the furnace is reduced below that of the atmosphere by means of a fan placed at (or near) the bottom of the chimney.

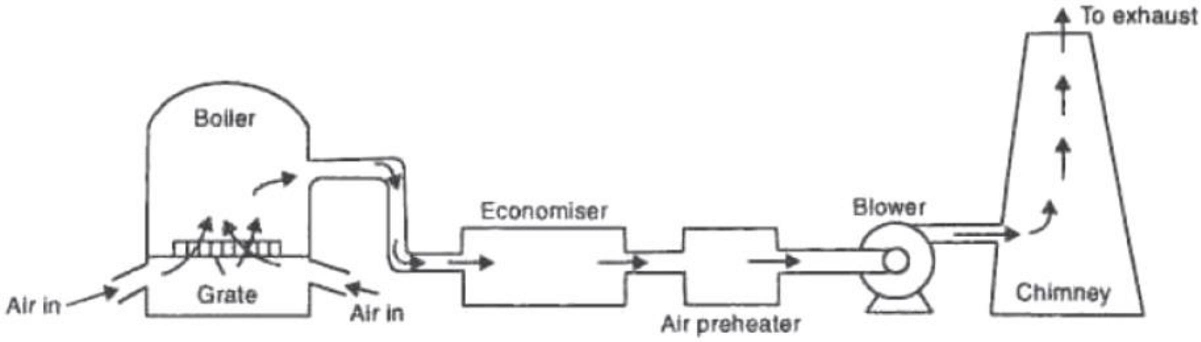


Figure: Induced fan draught

It draws the product of combustion from the furnace and forces them to pass through the chimney The action of induced draught is similar to the action of the chimney The arrangement of this system is shown in Fig.

(C) Balanced draught

Balanced draught is a combination of forced and induced draught. It is always better to use a combination of forced and induced draught instead of using either forced or induced draught alone. Here an air fan supplies air at a moderate pressure through the grate and also through the air-preheater.

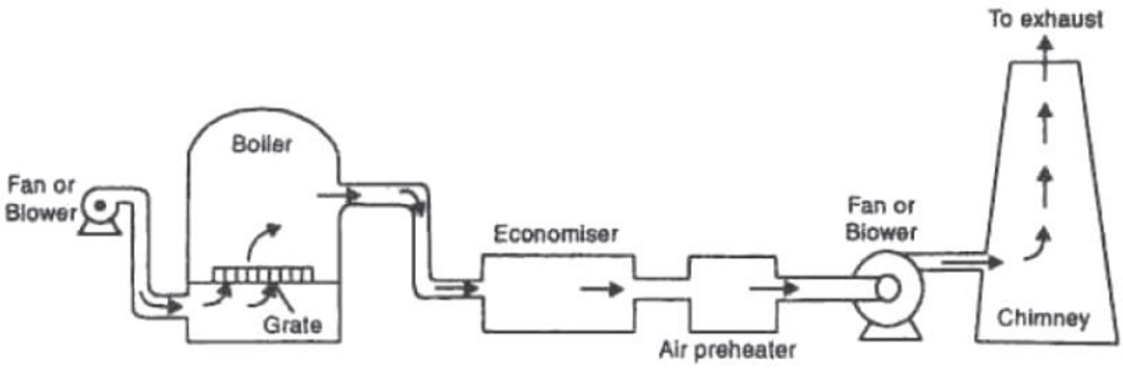


Figure: Balanced draught

An induced draught fan is placed at the bottom of the chimney to draw the flue gases through the flue tubes, economiser air-preheater and discharges them to atmosphere through chimney.

D) Steam Jet draught

The steam jet draught comes under the category of artificial draught. ¡t can also be classified in two categories:

. Forced steam jet draught
. Induced steam jet draught

In the forced steam jet draught, the draught is produced by placing the steam jet in the ash pit which is placed under the lire grate of the furnace. [n this case, the air will be forced into the furnace by the steam jet and the draught produced will be the forced draught.

The induced steam jet draught is produced when steam jet is directed into chimney from a nozzle placed in chimney. This causes the flow of gases through the fire tubes, ash pit and grate. Lnduced type steam jet draught is used in a locomotive boiler in which the exhaust steam from steam engine is passed through the nozzle to induce the air to pass through the fuel bed, furnace, flues and smoke box, thus creating a partial vacuum in the smoke box.

In case of forced steam jet draught as shown in Fig. (8.34) steam from boiler is throttled by a valve to a pressure of two bar and passed through the nozzles connected to a diffuser pipe. The steam comes out with high velocity from the diffuser and drags the column of air along with it and thus makes way for the fresh air to come inside the furnace.

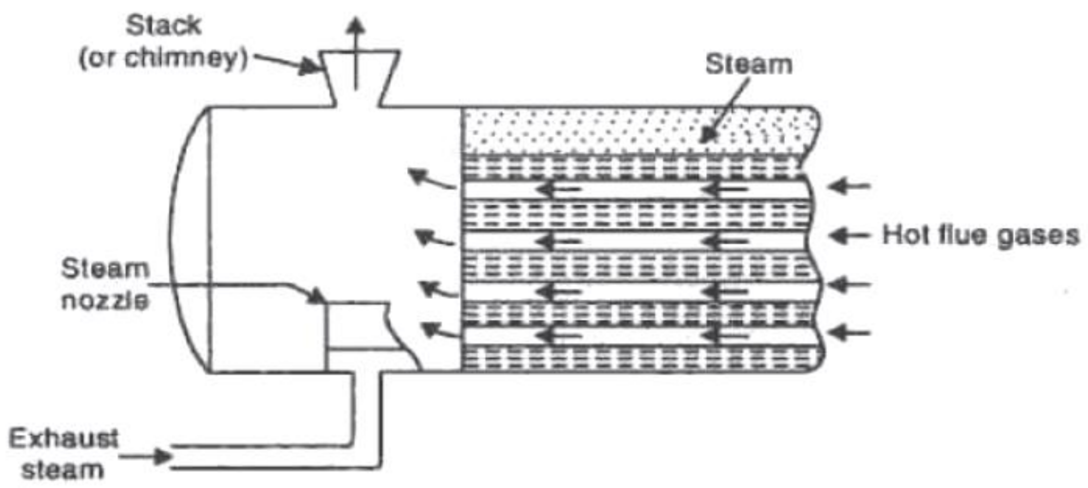


Figure: Steam Jet draught

Advantages of stcam jet draught
. Simple and economical
. Occupies little space
. Permits burning of inferior fuel
. No maintenance

Disadvantages

It can not start until steam at pressure is available

Advantages of Artificial Draught Over the Natural Draught

The artificial draught has the following advantages over the natural draught:

1.. Effective control over the combustion of fuel.
2. High rate of combustion
3. Permits burning of low grade fuel
4. Improves overall thermal efficiency of the plant
5. Reduces the height of chimney as it is only required to discharge the gases high in the atmosphere
6. Low consumption of fuel
7. Prevents smoke formation
8. Independent of atmospheric temperature
9. Enhances the evaporative capacity of boiler
10. It can be regulated as per the requirement of the furnace.

Disadvantage.

1. High installation cost
2. High running arid maintenance cost.
3. Permits burning of low grade fuel
5. Reduces the height of chimney as it is only required to discharge the gases high in the atmosphere

REFRIGERATION SYSTEMS [RGPV Jan 2008, june2012]

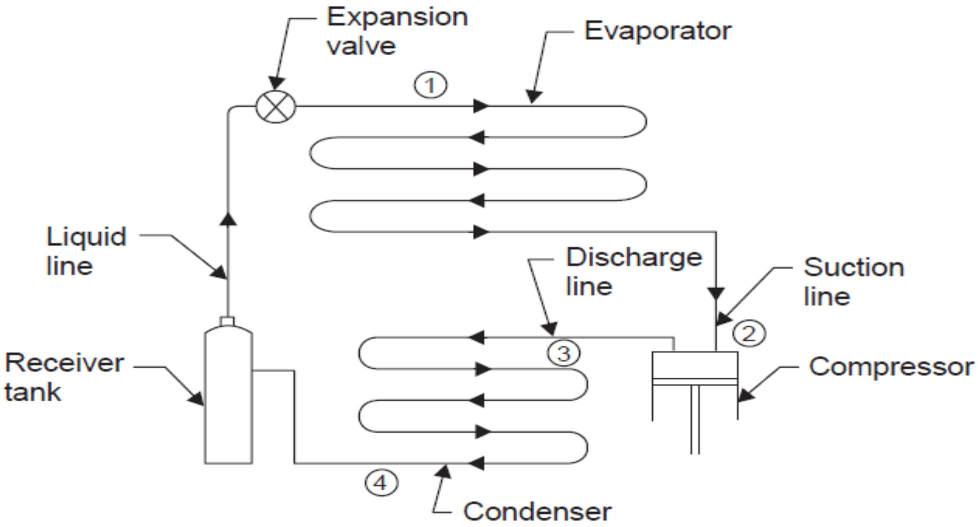
Refrigeration means the cooling of or removal of heat from a system. Refrigerators work mainly on two processes :
1. Vapour compression, and
2. Vapour absorption.

Simple Vapour Compression System :

In a simple vapour compression system the following fundamental processes are completed
in one cycle :

1. Expansion 2. Vaporization 3. Compression 4. Condensation.

The flow diagram of such a cycle



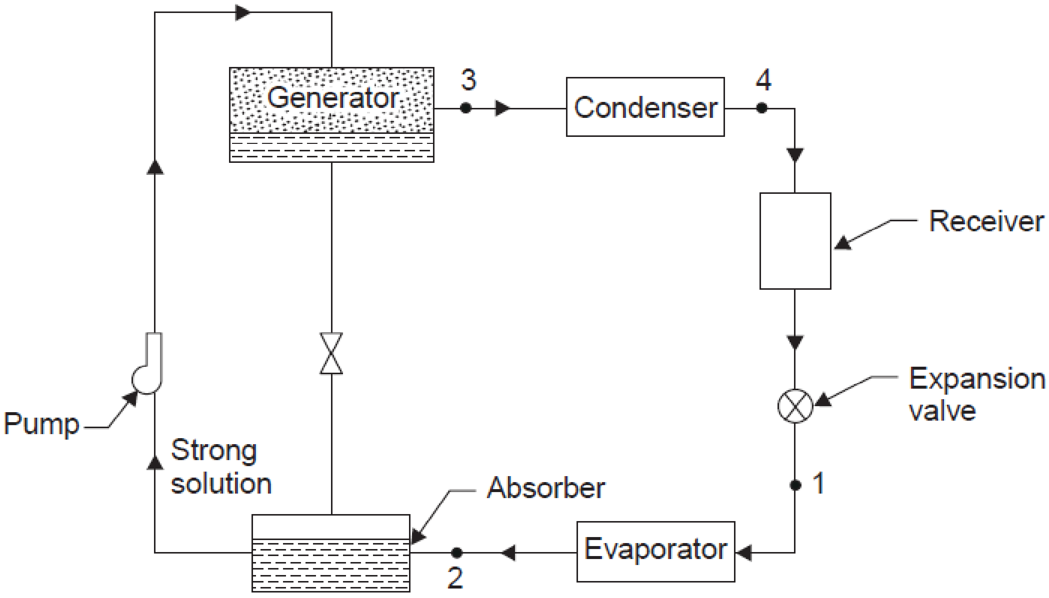
Vapour compression system.

The vapour at low temperature and pressure (state ‘2’) enters the “compressor” where it is compressed isentropically and subsequently its temperature and pressure increase considerably (state ‘3’). This vapour after leaving the compressor enters the ‘‘condenser” where it is condensed into high pressure liquid (state ‘4’) and is collected in a “receiver tank”. From receiver tank it passes through the “expansion valve”, here it is throttled down to a lower pressure and has a low temperature (state ‘1’). After finding its way through expansion “valve” it finally passes on to “evaporator” where it extracts heat from the surroundings or circulating fluid being refrigerated and vaporises to low pressure vapour (state ‘2’).

VAPOUR ABSORPTION SYSTEM

(Introduction)
In a vapour absorption system the refrigerant is absorbed on leaving the evaporator, the absorbing medium being a solid or liquid. In order that the sequence of events should be continuous it is necessary for the refrigerant to be separated from the absorbent and subsequently condensed before being returned to the evaporator. The separation is accomplished by the application of direct heat in a ‘generator’. The solubility of the refrigerant and absorbent must be suitable and the plant which uses ammonia as the refrigerant and water as absorbent will be described.
Simple Vapour Absorption System

In Fig. for a simple absorption system. The solubility of ammonia in water at low Temperatures and pressures is higher than it is at higher temperatures and pressures. The ammonia vapour leaving the evaporator at point 2 is readily absorbed in the low temperature hot solution in the absorber. This process is accompanied by the rejection of heat. The ammonia in water solution is pumped to the higher pressure and is heated in the generator. Due to reduced solubility of ammonia in water at the higher pressure and temperature, the vapour is removed from the solution. The vapour then passes to the condenser and the weakened ammonia in water solution is returned to the absorber.



Simple vapour absorption system.

In this system the work done on compression is less than in vapour compression cycle (since pumping a liquid requires much less work than compressing a vapour between the same
Pressures) but a heat input to the generator is required. The heat may be supplied by any convenient form e.g. steam or gas heating.

Steam (pure substance) [RGPV June 2008, Feb.2006]

A pure substance is a system which is (*i*) *homogeneous in composition*, (*ii*) *homogeneous in*
chemical aggregation, and (*iii*) *invariable in chemical aggregation*.

"Homogeneous in composition" means that the composition of each part of the system is the *same* as the composition of *every other part*. "*Composition* means the relative proportions of the chemical elements into which the sample can be analysed. It does not matter how these elements are combined.

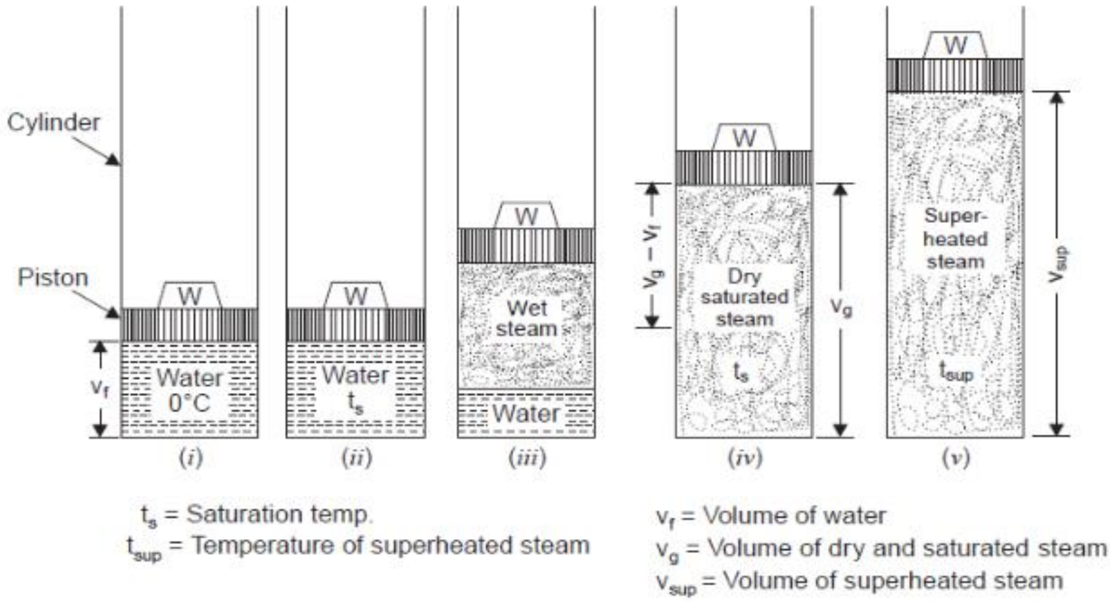
"Homogeneous in chemical aggregation" means that the chemical elements must becombined chemically in the same way in all parts of the system. Consideration of

Fig. again shows that the system (a) satisfies this condition also ; for steam and water consist of identical molecules. System (b) on the other hand is not homogeneous in chemical aggregation since in the upper part of the system the hydrogen and oxygen are not combined chemically (individual atoms of H and O are not uniquely associated), whereas in the lower part of the system the hydrogen and oxygen are combined to form water.

"Invariable in chemical aggregation" means that the state of chemical combination of the system does not change with time (condition (ii) referred to variation with position). Thus a mixture of hydrogen and oxygen, which changed into steam during the time that the system was under consideration, would not be a pure substance.

FORMATION OF STEAM

Consider a cylinder fitted with a piston which can move freely upwards and downwards in it. Let, for the sake of simplicity, there be 1 kg of water at 0°C with volume *vf* m^3 under the piston Fig. Further let the piston is loaded with load *W* to ensure heating at constant pressure. Now if the heat is imparted to water, a rise in temperature will be noticed and this rise will continue till boiling point is reached. The temperature at which water starts boiling depends upon the pressure and as such for *each pressure* (under which water is heated) *there is a different boiling point*. This boiling temperature is known as the temperature of formation of steam or *saturation temperature*.



It may be noted during heating up to boiling point that there will be slight increase in volume of water due to which piston moves up and hence work is obtained as shown in Fig. This work, however, is so *small* that is can be *neglected*. Now, if supply of heat to water is continued it will be noticed that rise of temperature after the boiling point is reached *nil* but piston starts moving upwards which indicates that there is increase is volume which is only possible if steam formation occurs. The heat being supplied does not show any rise of temperature but changes water into vapour state (steam) and is known as *latent heat* or *hidden heat*. So long as the steam is in contact with water, it is called *wet steam* Fig. and if heating of steam is further progressed as shown in Fig such that all the water particles associated with steam are evaporated, the steam so obtained is called *dry and saturated steam*. If *vg* m3 is the volume of 1 kg of dry and saturated steam then work done on the piston will be *p*(*vg* – *vf*) ... where *p* is the constant pressure (due to weight '*W*' on the piston). Again, if supply of heat to the dry and saturated steam is continued at constant pressure there will be increase in temperature and volume of steam. The steam so obtained is called *superheated steam* and it *behaves like a perfect gas*. This phase of steam formation is illustrated in Fig. Fig. shows the graphical representation of formation of steam.

T-s Diagram for a pure substance:

Consider the heating of 1 kg of ice at–5^{0}C to steam at 250^{0}C. The pressure being maintained at 1 atm. It is observed that the entropy of steam increases in different regimes of heating namely

1)Entropy increase of ice to saturated freezing temperature
2) Entropy increase of ice as it melts into water.
3) Entropy increase of water as it is heated from 0^{0}c to 100^{0}C.
4) Entropy increase of water as it is vaporized at 100^{0}C absorbing latent heat of vaporization.
5)Entropy increase of vapour as it is heated from 100^{0}C to 250^{0}C

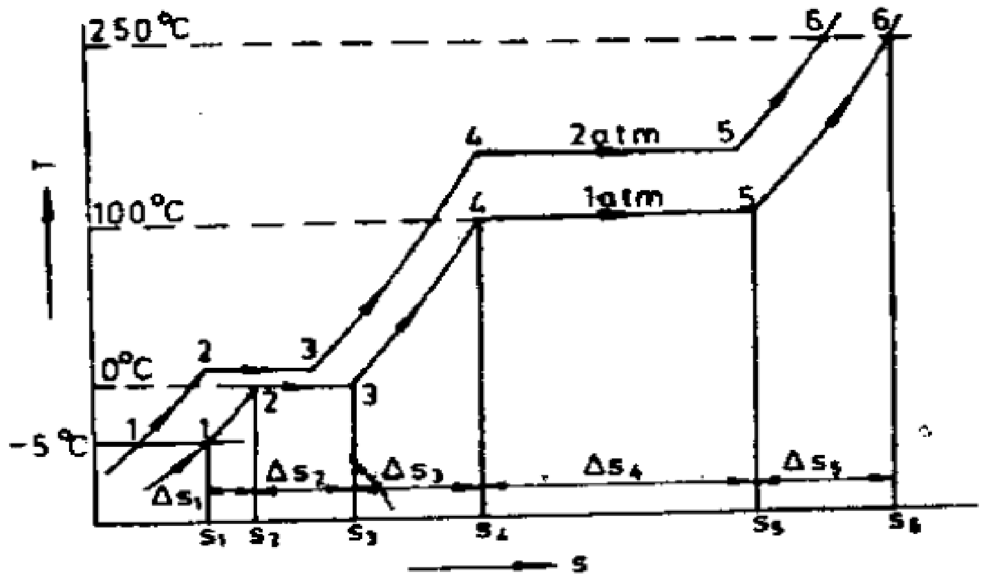
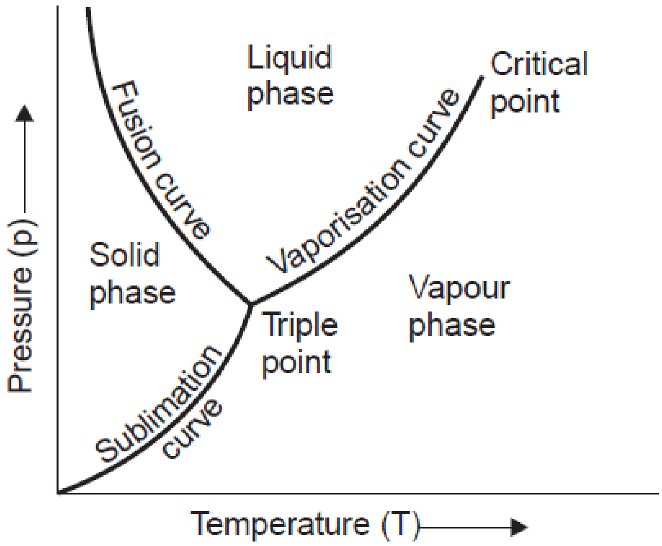


DIAGRAM FOR A PURE SUBSTANCE

P-T (Pressure-Temperature)

If the vapour pressure of a solid is measured at various temperatures until the triple point is reached and then that of the liquid is measured until the critical point is reached, the result when plotted on a p-T diagram appears as in Fig.
If the substance at the triple point is compressed until there is no vapour left and the pressure on the resulting mixture of liquid and solid is increased, the temperature will have to be



p-T diagram for a substance such as water.

changed for equilibrium to exist between the solid and the liquid. Measurements of these pressures and temperatures give rise to a third curve on the *p-T* diagram, starting at the triple point and continuing indefinitely.

The points representing the coexistence of
(i) Solid and vapour lie on the 'sublimation curve',
(ii) Liquid and vapour lie on the 'vaporization curve',
(iii) Liquid and solid lie on the 'fusion curve'.
In the particular case of water, the sublimation curve is called the frost line, the vaporization curve is called the steam line, and the fusion curve is called the ice line. The slopes of sublimation and the vaporization curves for all substances are positive. The slope of the fusion curve however may be positive or negative. The fusion curve of most substances has a positive slope. Water is one of the important exceptions.
Triple point
The triple point is merely the point of intersection of sublimation and vaporization curves. It must be understood that only on p-T diagram is the triple point represented by appoint.

On p-V diagram it is a line, and on a U-V diagram it is a triangle.
The pressure and temperature at which all three phases of a pure substance coexist may be measured with the apparatus that is used to measure vapour pressure.

Important terms relating steam formation

1. Sensible heat of water (hf).
It is defined as the quantity of heat absorbed by 1 kg of water when it is heated from 0°C (freezing point) to boiling point. It is also called total heat (or enthalpy) of water or liquid heat invariably.

2. Latent heat or hidden heat (hfg).

It is the amount of heat required to convert water at a given temperature and pressure into steam at the same temperature and pressure. It is expressed by the symbol hfg and its value is available from steam tables. The value of latent heat is not constant and varies according to pressure variation.

3. Dryness fraction (x).

The term dryness fraction is related with wet steam. *It is defined as the ratio of the mass of actual dry steam to the mass of steam containing it*. It is usually expressed by the symbol '*x*' or '*q*'.
If *ms* = Mass of dry steam contained in steam considered, and
mw = Weight of water particles in suspension in the steam considered,

Then,

$$x = \frac{m_s}{m_s + m_w}$$

4. Total heat or enthalpy of wet steam (h)

It is defined as the quantity of heat required to convert 1 kg of water at 0°C into wet steam at constant pressure. It is the sum of total heat of water and the latent heat and this sum is also called enthalpy.
$h = hf + xhfg$
If steam is dry and saturated, then $x = 1$
Then $hg = hf + hfg$.

5. Superheated steam.

When steam is heated after it has become dry and saturated, it iscalled superheated steam and the process of heating is called *superheating. Superheating is always carried out at constant pressure*. The additional amount of heat supplied to the steam during superheating is called as '*Heat of superheat*' and can be calculated by using the specific heat of superheated steam at constant pressure (*cps*), the value of which varies from 2.0 to 2.1 kJ/ kg K depending upon pressure and temperature. The total heat of superheated steam is given by

$$hsup = hf + hfg + cps\ (Tsup - Ts)$$

6. Volume of wet and dry steam.

If the steam has dryness fraction of x, then 1 kg of this steam will contain x kg of dry steam and $(1 - x)$ kg of water. If *vf* is the volume of 1 kg of water and *vg* is the volume of 1 kg of perfect dry steam (also known as specific volume), then volume of 1 kg of wet steam = volume of dry steam + volume of water.
$= xvg + (1 - x)vf$

Note. The volume of *vf* at low pressures is very small and is generally neglected. Thus is general, the volume of 1 kg of wet steam is given by, *xvg* and density1 /*xvg* kg/m3.

7. Volume of superheated steam.

As superheated steam behaves like a perfect gas its volume can be found out in the same way as the gases.

$$v_{sup} = \frac{v_g\, T_{sup}}{T_s}$$

External work done during evaporation
When water is evaporated to form saturated steam, its volume increases from vf to vg at a constant pressure, and thus external work is done by steam due to increase in volume. The energy for doing the work is obtained during the absorption of latent heat. This work is called external work of evaporation and is given by p (vg – vf). i.e., External work of evaporation = p (vg – vf) As at low pressure vf is very small and hence neglected, work of evaporation is
P. vg
In case of *wet* steam with dryness fraction *x*, work of evaporation will be
Pxvg

Some solve example on Properties of steam

Q.1 Calculate the internal energy per kg of superheated steam at a pressure of 10 bar and a temperature of of 300^{0}C Also find the change internal energy in this steam if expanded to 1.4 bar and dryness fraction 0.8.
[RGPV, June 2008 (10)]

Sol. Given, p_1 = 10 bar, t_{sup} 300°C. P2 = 1.4
From steam tables corresponding to a pressure of 10 bar,
hf = 7616 kJ/kg
hfg = 2013,6 kJ/kg
vg = 0.19430 m^3/kg
t = 179.9^{0}C
Enthalpy of 1 kg of superheated steam,
hsup = hf+ hfg + cp(tsup— t)
= 762.6 + 2013.6 + 2.1 (300 — 179.9) (cp = 2.1 kJ/kg for steam)
= 3028.41 kJ/kg

$$V\text{sup} = vg\frac{T\text{sup}}{T}$$

$$V\text{sup} = 0.1943\frac{(300+273)}{(179.9+273)}$$

= 0.2458 m3/kg

Internal energy of superheated steam
Vsup = hsup — 100 p1 Vsup
= 3028.41 — 100 x 10 x 0.2458

= 2782.61 kJ/kg Ans

The superheated steam now expands to a pressure of 1.4 bar. From steam tables corresponding to a pressure of 1.4 bar, we find that
hf= 458.4 kJ/kg,
hfg = 2231.9 kJ/kg,
Vg = 1.2363 m3/kg

Internal energy of the expanded steam,
Ue = hf + Xhfg 100P2 X Vg
= 458.4 + 0.8 x 2231.9 — 100 x 1. 4 x 0.8 x 1.2363
= 2105.45 kJ/kg

Change in internal energy
= Usup — Ue
= 2782.61 — 2105A5
= 677.16 kJ/kg Ans.

Q.2 Calculate the internal energy of 1 kg of steam at a pressure of 10 bar when steam is
(i) 0.8 dry
(ii) dry and saturated
(iii) Superheated to 250°C.
[RGPV, Nov./Dec. 2007 (10)]

Sol. Given, p = 10 bar,
Tsup = 250 + 273 = 523 K.
From steam tables, corresponding to a pressure of 10 bar, we find that
hf = 762.6 kJ/kg,
hfg = 2013.6 kJ/kg
vg = 0.1943 m3/kg,
tg = 179.88°C, Tg = 179.88 + 273 = 452.88 K
(1) Internal energy of I kg of steam when it is 0.8 dry
Internal energy for wet steam
Uwet = hf + xhfg — 100 p x vg
= 762.6 + 0.8 x 2013.6 — 100 x 10 x 0.8 x 0.1943
= 2218.04 kJ Ans.
(ii) Internal energy of l kg of steam when it is dry and saturated

Internal energy for dry saturated steam Udry = hf + hfg — 100 Pvg
= 762.6 + 2013.6 — 100 x 10 x 0.1943

= 2581.9 kJ Ans.

(iii) Internal energy of I kg of steam when it is superheated to 250°C

Volume of superheated steam

$$Vsup = vg\frac{Tsup}{T}$$

$$Vsup = 0.1943\frac{523}{45288}$$

Vsup = 0.2244 m3/kg

Enthalpy of 1 kg of superheated steam

hsup = hf + hfg + cp (tsup — tg)
= 762.6 + 2013.6 + 2.1 (250 — 179.88)
= 2923.452 kJ (cp for superheated steam = 2.1 kJ/kgK)

Internal energy of superheated steam

Usup = hsup — 100 p Vsup
= 2923.452 - 100 x 10 x 0.2244
= 2699.052 kJ Ans.

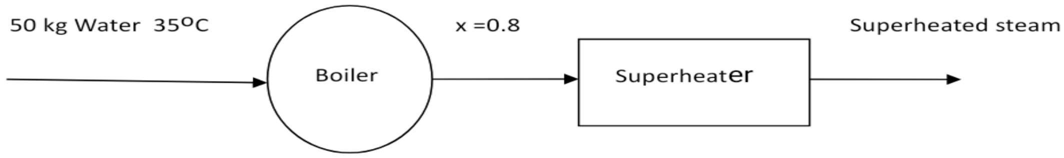
Question. 3. A sperical shell of capacity 0.10 m^3 contains steam and water in equal volume. If the temperature of the steam is 300°C. Determine the mass of water and steam in the container. Also calculate the dryness fraction of the wet steam.

Solution

Total volume of the shell is 0.1 m^3
Volume occupied by steam =V_s= 0.05 m^3
Volume occupied bywater =V_w= 0.05 m^3
From steam tables, at saturation temperature of 300 °C
v_f=0.0014 m^3/kg; v_g=0.0217m^3/kg
mass of water = V_w/ v_f = 0.05/0.0014 =35.71kg
mass of steam = V_s/ v_g = 0.05/0.0217 =2.30 kg
dryness fraction x x = mass of steam/ (mass of steam + mass of water)
x x = 2.30/35.71= 0.06 Answer

Question 4. Determine the quantity of heat energy required to produce 50 kg of steam at a pressure of 10 bar and dryness fraction 0.8 from water at 35° C. Also calculate the heat added in superheater if the steam is passed through superheater where its temperature is raised to 250 °C. Assume no pressure loss takes place in the superheater. C_{ps}=2.3 kJ/kgK.

Solution



From steam tables, at saturation pressure of 10 bar

T_s=179.9 °C; h_f=762.8 kJ/kg; h_{fg}=2015.3 kJ/kg; h_g=2778.1kJ/kg

Dryness fraction of steam produced in the boiler = x x = 0.8

Specific enthalpy of wet steam

h= h_f + x x h_{fg}

h=762.8 + 0.8×2015.3 kJ/kg= 2375.04 kJ/kg

Heat energy added per kg of steam produced = h-enthalpy of water at 35°C

Assume specific heat of water = 4.18 kJ/kg K

2375.04-4.18×35=2228.74kJ/kg;

Hence heat energy required to produce 50 kg of the steam = m×h

= 50 ×2228.74=111437 kJ Answer

Specific enthalpy of superheated steam = h_g+C_{ps}(T_{sup}-T_s)

Substituting the values h_{sup}= 2778.1 + 2.3(250-179.9) = 2939.33kJ/kg

Heat energy added in the superheater per kg of steam = h_{sup}-h

= 2939.33-2375.04= 564.29 kJ/kgK

Total heat energy added in the superheater for 50 kg

= 50×564.29=28214.5 kJ. Answer

Question 5. A pressure cooker contains 1 kg of saturated steam at a pressure of 0.4 MPa. Determine the quantity of heat that must be rejected so that the final condition of steam in the cooker is 0.5 dry.

Solution

From steam tables, at saturation pressure of 0.4 MPa = 4 bar

T_s=143.6 °C; h_f=604.7 kJ/kg; h_{fg} = 2133.8 kJ/kg ; h_{g1}= 2738.5kJ/kg ; v_f = 0.001084; v_{g1}= 0.463;

v_1 = v_{g1}= 0.463; h_1=h_{g1}

Neglecting the volume occupied by water

$v_1 = v_{g1}$ is the initial volume as the steam is saturated, let v_2 be the volume after the heat is removed.

$v_1 = v_2$ as the process of cooling is taking place at constant volume.

Since the dryness fraction of steam after cooling = x x = 0.6 where v_{g2} is the specific volume of steam at condition 2

v_2 = x x v_{g2}= 0.5 v_{g2} since $v_1=v_2$

v_1=0.5 v_{g2} ; v_{g2} = 0.926m^3/kg

from steam tables corresponding to the value of v_{g2} (taking the nearest values)

T_s=118.6 °C; h_{f2}=497.8 kJ/kg; h_{fg2}=2206.5 kJ/kg ; h_{g2}=2704.3kJ/kg

$h_2 = h_{f2}$ + x x h_{fg2}= 497.8 +0.5×2206.5 = 1601 kJ/kg;

heat energy removed = h_1-h_2

2738.5-1601= 1137.5 kJ Answer

Question 6. A vessel of 1 m^3 contains wet steam at a pressure of 8 bar and dryness fraction of 0.9. Steam is blown off from the vessel until the pressure drops to 4 bar. Assume that the enthalpy of steam per kg remains constant in the vessel during the blow off. Determine the mass of the steam blown off.

Solution :

Given volume of the vessel v_1 = 1.0 m^3; $x_1 x_1$ = 0.9;

From steam tables, at saturation pressure of 8 bar

T_s=170.4 °C; h_{f1}=721.1 kJ/kg; h_{fg1}=2048 kJ/kg ; h_{g1}= 2769.1kJ/kg ; v_f = 0.001115; v_{g1}= 0.240;

From steam tables, at saturation pressure of 4 bar

T_{s2}=143.6 °C; h_{f2}=604.7 kJ/kg; h_{fg2}=2133.8 kJ/kg ; h_{g2}=2738.5kJ/kg ; v_{f2} =0.001084; v_{g2}=0.463;

Neglecting the volume occupied by water

The mass of the steam in the vessel = m_1 = v_1 /$x_1 x_1$ v_{g1}= 1.0/(0.9X0.24)=4.629 kg

Since the enthalpy in the vessel remains same before and after the blow off of the steam

$h_1=h_2$

h_{f1} + $x_1 x_1$ h_{fg1} = h_{f2} + $x_2 x_2$ h_{fg2}

$x_2 x_2$ = 0.918

Mass of steam present in the vessel after blowing off of the steam = m_2=v1 /x_2 v_{g2} = 1/0.918×0.463 = 2.352 kg

Mass of steam blown off = m_1- m_2= 4.629-2.352=2.277 kg Answer

Question 7. A sample of steam at a pressure of 10 bar is passed through a throttling calorimeter for measuring the dryness fraction. If the pressure and temperaure recorded after the throttling is found to be 1 bar and 120°C. Determine the dryness fraction of steam. Take the value of specific heat of steam =2.3 kJ/kgK.

Solution:

From steam tables, at saturation pressure of 10 bar

T_{s1}=179.9 °C; h_{f1}=762.8 kJ/kg; h_{fg1}=2015.3 kJ/kg ; h_{g1}=2778.1kJ/kg ;

At saturation pressure of 1 bar

T_{s2} = 99.6 °C; h_{g2}=2675.5 kJ/kg ;

Let $x_1 x_1$ be the dryness fraction of steam before thrrottling and h_1 the enthaly before throttling

$h_1 = h_{f1} + x_1 x_1\ h_{fg1} = 762.8 + x_1 x_1\ 2015.3$ kJ/kg;

as the temperature after throttling (T_2 = 120°C) is more than the saturation temperature of steam at outlet pressure i.e. T_{s2} steam is superheated. The enthalpy at outlet h_2

$$h_2 = h_{g2} + C_{ps}(T_2 - T_{s2})$$

$$h_2 = 2675.5 + 2.3(120 - 99.6) =$$

h_1=h_2 for throttling process i.e. enthalpy remains constant

$$762.8 + x_1 x_1\ 2015.3 = 2722.42$$

The dryness fraction of steam $x_1\ x_1$ = 0.97 Answer

Ques. 8 In the above example what is the maximum possible moisture that could be measured in percentage, if minimum 5 degree of superheat is required after throttling for the above set setup.

Solution:

Since 5 degree of superheat is required the outlet temperature recorded should be 5°C more than the saturation temperature (T_{s2}) corresponding to the outlet pressure.

$T_2 = T_{s2} + 5 = 99.6 + 5 = 104.6$°C;

$h_2 = h_{g2} + C_{ps}(T_2 - T_{s2})$

$h_2 = 2675.5 + 2.3(104.6 - 99.6) = 2687$

as h_1=h_2 for throttling process

$762.8 + x_1 x_1 \times 2015.3 = 2687$;

$x_1 x_1 = 0.95$.

The maximum moisture content which can be measured with the given setup is 5%

REFRIGERANTS[RGPV june 2012]

A 'refrigerant' is defined as any substance that absorbs heat through expansion or vaporisation and loses it through condensation in a refrigeration system. The term 'refrigerant' in the broadest sense is also applied to such secondary cooling mediums as cold water or brine, solutions. Usually refrigerants include only those working mediums which pass through the cycle of evaporation, recovery, compression, condensation and liquefaction. These substances absorb heat at one place at low temperature level and reject the same at some other place having higher temperature and pressure. The rejection of heat takes place at the cost of some mechanical work. Thus circulating cold mediums and cooling mediums (such as ice and solid carbon dioxide) are not primary refrigerants. In the early days only four refrigerants, Air, ammonia (NH3), Carbon dioxide (CO2), Sulphur dioxide (SO2), possessing chemical, physical and thermodynamic properties permitting their efficient application and service in the practical design of refrigeration equipment were used. All the refrigerants change from liquid state to vapour state during the process.

Classification of Refrigerants
The refrigerants are classified as follows:
1. Primary refrigerants.
2. Secondary refrigerants.

1. Primary refrigerants are those working mediums or heat carriers which directly take part in the refrigeration system and cool the substance by the absorption of latent heat e.g. Ammonia, Carbon dioxide, Sulphur dioxide, Methyl chloride, Methylene chloride, Ethyl chloride and Freon group etc.

2. Secondary refrigerants are those circulating substances which are first cooled with the help of the primary refrigerants and are then employed for cooling purposes, e.g. ice, solid carbon dioxide etc. These refrigerants cool substances by absorption of their sensible heat.

The primary refrigerants are grouped as follows:

(*i*) Halocarbon compounds. In 1928, Charles Kettening and Dr. Thomas Mighey invented and developed this group of refrigerant. In this group are included refrigerants which contain one or more of three halogens, chlorine and bromine and they are sold in the market under the names as *Freon, Genetron, Isotron*, and *Areton*. Since the refrigerants belonging to this group have outstanding merits over the other group's refrigerants, therefore they find wide field of application in domestic, commercial and industrial purposes.
The list of the halocarbon-refrigerants commonly used is given below:
R-10 — Carbon tetrachloride (CCl4)
R-11 — Trichloro-monofluoro methane (CCl3F)
R-12 — Dichloro-difluoro methane (CCl2F2)
R-13 — Mono-bromotrifluoro methane (CBrF3)
(*ii*) Azeotropes. The refrigerants belonging to this group consists of mixtures of

different substances. These substances cannot be separated into components by distillations. They possess fixed thermodynamic properties and do not undergo any separation with changes in temperature and pressure. An azeotrope behaves like a simple substance.

Example. R-500. It contains 73.8% of (R-12) and 26.2% of (R-152).

(*iii*) Hydrocarbons. Most of the refrigerants of this group are organic compounds. Several hydrocarbons are used successfully in commercial and industrial installations. Most of them possess satisfactory thermodynamic properties but are highly inflammable. Some of the important refrigerants of this group are:
R-50 — Methane (CH4)
R-170— Ethane (C2H6)
R-290— Propane (C2H8)

(*iv*) Inorganic compounds. Before the introduction of hydrocarbon group these refrigerants were most commonly used for all purposes.
The important refrigerants of this group are :
R-717— Ammonia (NH3)
R-718— Water (H2O)
R-729— Air (mixture of O2, N2, CO2 etc.)

(*v*) Unsaturated organic compound. The refrigerants belonging to this group possess ethylene or propylene as their constituents. They are:
R-1120 — Trichloroethylene (C3H4Cl3)
Properties of an ideal refrigerant

1. Thermodynamic properties:
(*i*) Low boiling point
(*ii*) Low freezing point
(*iii)* Positive pressures (but not very high) in condenser and evaporator.
(*iv*) High saturation temperature
(*v*) High latent heat of vaporization.

2. Chemical Properties:
(*i*) Non-toxicity
(*ii*) Non-flammable and non-explosive
(*iii*) Non-corrosiveness
(*iv*) Chemical stability in reacting
(*v*) No effect on the quality of stored (food and other) products like flowers, with other materials *i.e.*, furs and fabrics.

(*vi*) Non-irritating and odourless.

3. Physical Properties:

(*i*) Low specific volume of vapour
(*ii*) Low specific heat
(*iii*) High thermal conductivity
(*iv*) Low viscosity
(*v*) High electrical insulation.

Eco-friendly refrigerant

Refrigeration applications at the domestic, commercial and industrial levels are becoming an integral part of the present day living. The demand and supply of refrigeration systems is increasing day by day with the changing lifestyle. The existing compressor-based refrigeration (Le. mechanical refrigeration) system has reached the maximum level of innovation. For the last few decades, there has not been any significant increase in the efficiency (Le., coefficient of performance, COP) of the system. Moreover, with the increasing awareness of environmental degradation, the production, use and disposal of ChloroFluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as re-frigerants in mechanical refrigeration system has become a subject of great concern. However, such systems are being developed using more ecofriendaly refrigerants viz., air, CO2, NH3, etc. Besides, efforts are being directed to develop other types of refrigeration technologies e.g., magnetic refrigeration, thermoelectric refrigeration (discussed in Part 1) and thermo acoustic refrigeration (discussed in Part 2), which will be more ecofriendly, cost effective, efficient, simple in design, convenient and reliable.

Height of chimney

The natural draught produced in a boiler depends on the height of the chimney and the difference between the temperature of the hot flue gases leaving the boiler and that of the outside cold air. An expression showing the relationship between the chimney height and draught
produced by it in terms of temperature of outside air and temperature of the flue gases is deduced below:
let
m = mass of air in kg per kg of fuel (or mass of air used in kg to burn 1 kg of fuel)
T= absolute temperature of the flue gases inside the chimney in K
T_1 absolute temperature of air outside the chimney in K
Therefore
Mass of chimney gases = (m+1) kg per kg of fuel,

The volume of flue gases produced may be taken equal to the volume of air supplied

Volume per kg of flue gases at 0°C (273K) volume per kg of air at 273 K
As we know

PV= m RT where value of R (for air) = 287 kJ/kg K

$$V = \frac{RT}{P}$$

$$V = \frac{287x273}{1.01325x10^3}$$

V = 0.7734 m3/kg.

The pressure difference being very small, the pressure can be treated as constant at furnace and chimney base for the purpose of volume calculation at higher temperature.

As we know from Charles's law -
Volume of a gas is proportional to its absolute temperature"

V □ T

$$\frac{V}{T} = \frac{V_1}{T_1}$$

$$V_1 = \frac{VT_1}{T}$$

The volume per kg of air at temperature $T_1 = \frac{0.7734\,T_1}{273}$

$\therefore$ Volume of m kg of air at temperature $T_1 = \frac{0.7734 m T_1}{273}$

and volume of chimney gases at temp. $T = \frac{0.7734 m T}{273}$ per kg of fuel burnt ..

Therefore the density of air at T_1 = mass/volume

$$= \frac{m}{(0.7734mT_1)/273}$$

$$= 1.293\left(\frac{273}{T_1}\right)\text{kg/m}^3$$

Mass density of chimney gases at $T = \dfrac{\text{Mass of chimney gases}}{\text{Volume of chimney gases}}$

$$\rho = \frac{m+1}{(0.7734mT)/273}$$

$$\rho = 1.293\ \frac{m+1}{m} \times \frac{273}{T} \quad \text{..............1}$$

Let H be the height of the chimney required in metres measured from the grate level.

The pressure exerted per square metre at the furnace grate level by a column of hot gas of 1 metre in height = density of the gas;

∴ Pressure exerted by a column of hot air of H metre height

$$= \text{density} \times \text{height} \times g$$

$$= \rho g H\ \text{N/m}^2 \quad \text{..........................2}$$

Substituting ρ from equation 1 and 2

$$= 1.293\frac{m+1}{m} \times \frac{273}{T} \times gH\ \text{N/m}^2 \quad \text{...........3}$$

Similarly pressure exerted by a column of cool air of H metre height from equation (8.3)

$$= 1.293 \times \frac{273}{T_1} \times gH\ \text{N/m}^2 \quad \text{............4}$$

Since the pressure causing the draught is due to the difference of pressure between the hot gas column in chimney of height H and cool air column outside the chimney of height H.

$$\therefore\ p = \{1.293 \times \frac{273}{T_1} \times gH - \{1.293\frac{m+1}{m} \times \frac{273}{T} \times gH\}\ \text{N/m}^2$$

$$p = 1.293 \times 273 \times gH\left\{\frac{1}{T_1} - \left[\frac{m+1}{m}\right] \times \frac{1}{T}\right\}\text{N/m}^2$$

Thus mass of hot gases discharged in a given time i proportional to the product of its density and velocity of its discharge.
Le., Mass of hot gases discharged (M,) x velocity (V) x density ρ)

From the equations given in the box it is clear that the velocity is proportional to square root of h_G and density is inversely proportional to temperature T

i.e., velocty $\propto \sqrt{h_G}$ and density $\propto 1/T$

Thus, mass of hot flue gases discharged for a given height of chimney $\alpha \sqrt{h_G} \propto \frac{1}{T}$

$$M_f \propto \sqrt{H\left\{\left[\frac{m}{m+1}\right]\frac{T}{T_l}-1\right\}} \propto 1/T$$

$$M_f = \text{constant} \sqrt{H\left\{\left[\frac{m}{m+1}\right]\frac{1}{TT_l}-\frac{1}{T^2}\right\}} \quad \text{......................5}$$

The only variable in equation (8.12) are M_f and T whereas atmospheric temperature T_l, height of chimney H and cross section area of chimney A are constants.

To find out the maximum discharge, differentiate equation (8.12) with respect to variable temperature T and equating it to zero, we get

$$\frac{dM_f}{dT} = \text{constant} \times \frac{1}{2}\left[\frac{-\left[\frac{m}{m+1}\right]\left\{\frac{1}{T_1}\times\frac{1}{T^2}+\frac{1}{T^3}\right\}}{\sqrt{\frac{m}{m+1}\frac{1}{T^2T_1}-\frac{1}{T^2}}}\right] = 0$$

$$\therefore \quad -\left[\frac{m}{m+1}\right]\left[\frac{1}{T_1}\times\frac{1}{T^2}+\frac{2}{T^3}\right] = 0$$

$$\therefore \quad T = 2\left[\frac{m+1}{m}\right]T_l \quad \text{................6}$$

On substituting for T in equation

$$h_G = H\left\{\left[\frac{m}{m+1}\right]\frac{T}{T_1}-1\right\}$$

$$h_0 = H\left\{\left(\frac{m}{m+1}\right)\frac{2\left(\frac{m}{m+1}\right)T_1}{T_1} - 1\right\}$$

$\therefore$ $\boxed{h_0 = H}$ for maximum discharge

Thus for maximum discharge the height of hot gas column producing the draught is equal to the height of the chimney.

Now substituting the value T in equation 6

$$h = 353\ H\left\{\frac{1}{T_1}\left[\frac{m+1}{m}\right]\right\}$$

and for max. discharge the temp. T from equation ....6 is $T = 2\left(\frac{m+1}{m}\right)T_1$

$$\therefore\ h = 353\ H\left[\frac{1}{T_1} - \left(\frac{m+1}{m}\right)\left(\frac{m}{m+1}\right)\frac{1}{2T_1}\right] = 353\ H\left[\frac{1}{T_1} - \frac{1}{2T_1}\right]$$

$\therefore$ for maximum discharge

$$\boxed{h = \frac{353H}{2T_1} = \frac{176.5H}{T_1}} \quad \text{....................7}$$

Q.1 A boiler is provided with a chimney of 24 m height. The ambient temperature is 25^{0}C. The temperature of flue gases passing through the chimney is 300^{0}C. If the air flow the combustion chamber is 20 kg/kg of fuel burnt, find (1) the theoretical draught in cm of water (2) velocity of flue gases passing through the chimney if 50% of theoretical draught is lost in friction at grate and passage. [RGPV, June 2005 (10)]

Sol^n :

Given : Height of chimney ,H = 24 m

Ambient temperature ,Ta = 25^{0}C 25+273 = 298 k

Amount of air flow, m = 20 kg/kg of fuel

Theoretical draught in the cm of water

$$h = 353\ H\left[\frac{1}{Ta} - \frac{1}{Tg}\left(\frac{m+1}{m}\right)\right]$$

$$h = 353 \times 24 \left[\frac{1}{298} - \frac{1}{573}\left(\frac{20+1}{20}\right)\right]$$

h = 12.9 mm of water Or 1.29 cm of water. Ans.

The equivalent gas head is given by

$$H' = H\left[\left(\frac{m}{m+1} \times \frac{Tg}{Ta}\right) - 1\right]$$

$$= 24\left[\left(\frac{20}{20+1} \times \frac{573}{298}\right) - 1\right]$$

= 19.5 m

Velocity of the flue gases passing through the chimney if 50% of the theoretical draught is lost in friction at the grate and passage

Available head = H' x friction loss

= 19.5 x 0.5 = 9.975 m.

Velocity of flue gases V = 4.43 $\sqrt{Availablehead}$

= 19.95 x 0.5 = 9.975

Q.2 Calculate the height of chimney required to produce a draught equivalent to 1.7 cm of water if the flue gas temperature is 270^{0}C and ambient temperature is 22^{0}C and minimum amount of air per kg of fuel is 17 kg. [RGPV, Dec. 2003 (5)]

Sol.

Given m = 17 kg

H = 1.7 cm of water = 17 mm of water

Flue gas temperature, Tg = 270^{0}C = 270 + 273 = 543 k

Ambient temperature Tg = 22^{0}C = 22 + 273 = 295 k

Draught $$h = 353\, H\left[\frac{1}{Ta} - \frac{1}{Tg}\left(\frac{m+1}{m}\right)\right]$$

$$h = 353\, H\left[\frac{1}{295} - \frac{1}{543}\left(\frac{17+1}{17}\right)\right]$$

$$H = \frac{17}{0.5083}$$

= 33.44m Ans.

If you have any queries please visit- https://studywithakash.in/

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THANK YOU