CHAPTER -1
FUNDAMENTAL CONCEPTS

Introduction

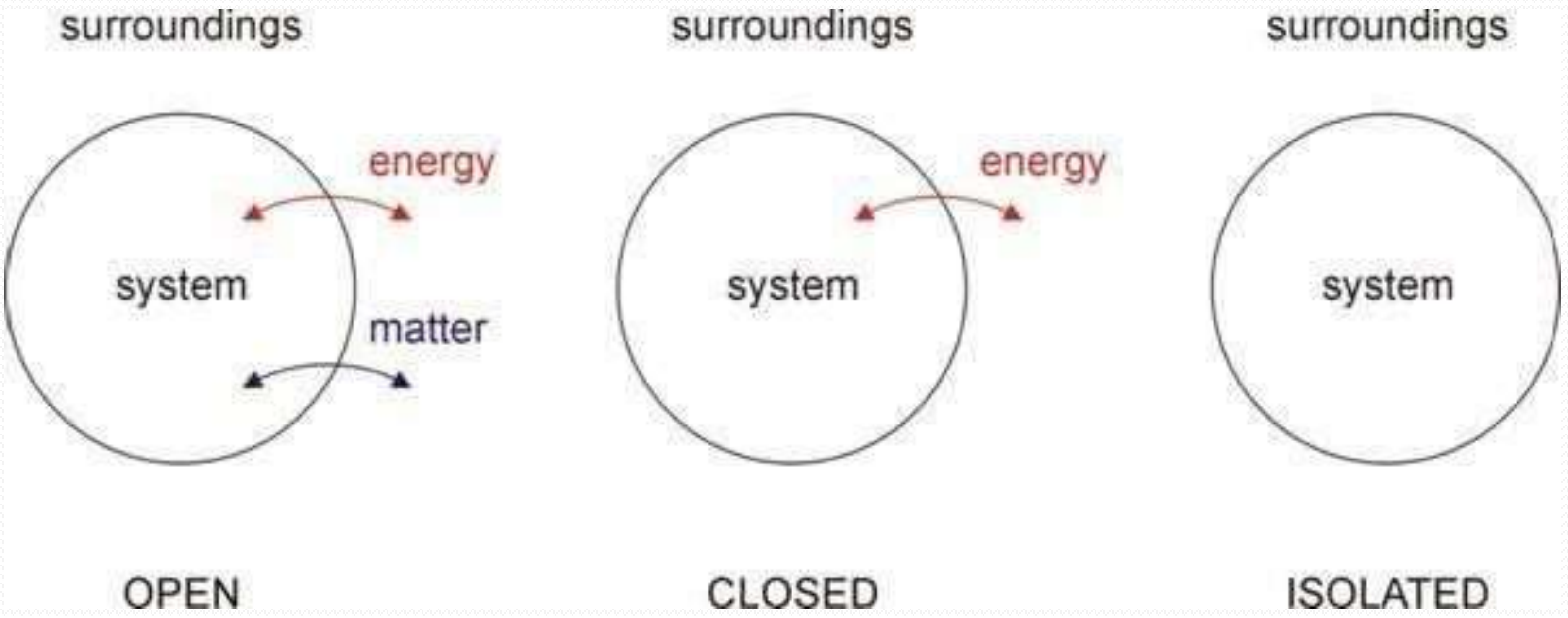
- Two Greek words constitute together Thermodynamics. These two words are, “Therme” means *Heat* and “Dynamics” means *motion*. The name clearly indicates that it is about the flow or motion of heat.It establishes the relationship between thermal (heat) and mechanical work(energies) and the properties of substances that have a relationship between heat and work.
- Thermodynamics State: Thermodynamics state at any point of time is that state at which the properties of the thermodynamic system such as pressure, temperature, volume etc. has a particular value. The system is said to exist in a particular state with a particular set of properties.

- Thermodynamic System:-It is defined as quantity of matter or a region in space chosen for study.
- Boundary: The real or imaginary envelope surrounding the system is termed as boundary. It separates the system from surrounding.
- Surrounding:- Any space or region outside this boundary is called surrounding.
- Universe: When System and surroundings are considered together constitute the universe

Thermodynamic systems

- Thermodynamic systems are classified as follows:-
- Closed System
- Open System
- Isolated System
- Homogeneous system
- Heterogeneous system
- Macroscopic system
- Microscopic system
- Closed System:- In Closed system mass/matter does not cross the boundary of the system but energy can move in out of the system i.e. exchange of energy between system and surrounding can take place but exchange of mass does not happen.
- Example:-Bomb calorimeter,Refrigerator etc.

- Open System: It is that system in which mass/matter and energy both can leave or enter the system i.e. the exchange of energy and mass takes place in open system. Example of open system is “Heating of water in an open container in which both mass and energy crosses the boundary of the system.
- Isolated System: In this system neither energy nor mass crosses the boundary of the system i.e. there no interaction between system and surrounding of any kind.


surroundings
energy
system
matter
OPEN
surroundings
energy
system
CLOSED
surroundings
system
ISOLATED

- Homogeneous System:- If the matter in the system exists in a single phase throughout, the system is said to be homogeneous. In this system the chemical and physical properties of the matter are same in all parts of the system. For example water, milk or mixture of water and milk.
- Heterogeneous System:- If the matter in the system exists in two or more phases is said to be heterogeneous system or in other words matter is not uniform throughout the system. A mixture of Ice and water is an example of Heterogeneous system.
- Macroscopic System:- Macroscopic means big, when we study the system by taking a particular quantity of matter as a whole without considering what is happening at molecular level in that quantity of matter, is termed as macroscopic system.
- Microscopic System:- Micro means small. This approach is opposite of Macroscopic approach.

Properties of system

To describe a system, it is necessary to know some of quantities which are charactertics of it. These quantities are called properties.

- Thermodynamic properties may be classified as follows:-
- Intensive or Intrinsic Properties: The properties which are independent of mass of the system are termed as Intensive properties i.e . they remain unchanged even in the variation of mass of the system. Temperature, Pressure, Density, Viscosity, thermal conductivity etc comes under this category.
- Extensive or Extrinsic Properties: The properties which are mass or size dependent are termed as Extensive properties. They have different values at different values of mass of the system. Volume, Energy, Enthalpy, Entropy etc. is the examples of Extensive properties.

Thermodynamic equilibrium

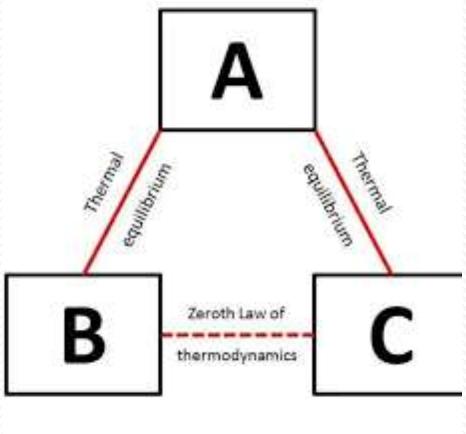
- Thermodynamic Equilibrium
- A thermodynamic system exists in equilibrium if there is no change in macroscopic properties is observed i.e. there is no interaction of the system with the surrounding, system remains isolated from the surrounding.
- In the course of time an isolated system always undergoes a change under the external means, it never undergoes a change on its own.
- A system is said to in equilibrium if the followings three conditions are satisfied:-
- Mechanical Equilibrium: No unbalancing force
- Thermal Equilibrium: Uniform Temperature
- Chemical equilibrium: No chemical reaction

Quasi-static process

- Quasi-static process
- A quasi static process is carried out in such a way that at every instant that the deviation of the system from thermodynamic equilibrium is infinitesimally small.
- Quasi - static Process
- A quasi static process can be explained by taking an example of gas is enclosed within a cylinder and piston arrangement having weight over the piston. The system initially in equilibrium state with properties $P_{1,}$ V_1, and $T_{1.}$ In equilibrium state the upward force exerted by the gas is just balanced by the weights on the piston. On removal of the weights from the piston unbalance of force between system and surrounding make the piston to move up due to the gas pressure till it hits the stop.

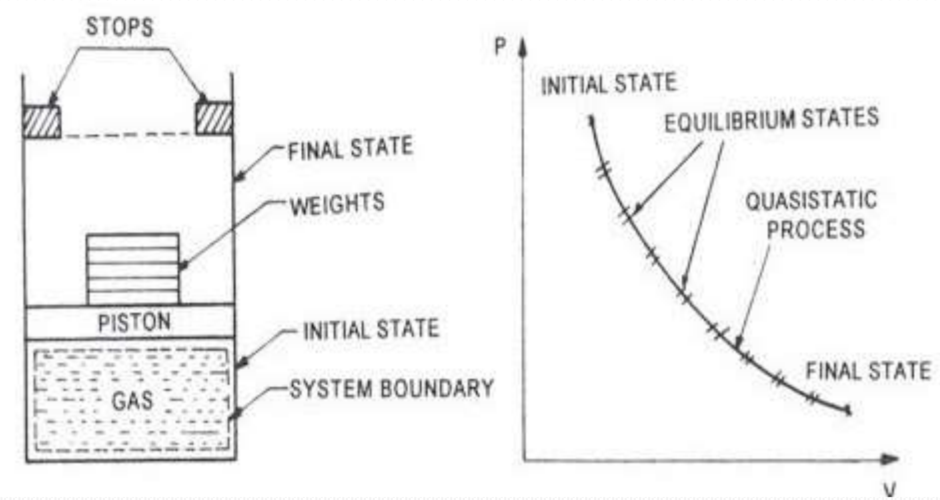
Zeroth law

- Zeroth law :-



- This law states that if body A is in thermal equilibrium with body B and also in thermal equilibrium with body C then body B and body C will also be in thermal equilibrium with each other. This law gives the basis of measurement of temperature.

- . The system again comes to an equilibrium states with new values of properties $P_{2,}$ V_2, and $T_{2.}$ The intermediate states between these two equilibrium states are non -equilibrium states, cannot be described by thermodynamic co-ordinates. But now suppose if in place of single weight, we put a number of small weights and the weights are removed one by one very slowly from the piston, in this case with the deviation from the equilibrium state will be infinitesimally small. Every state thus passed by the system will be an equilibrium state. Such a process having all these equilibrium states is known as quasi static process. All Quasi- static processes are reversible.


STOPS
FINAL STATE
WEIGHTS
PISTON
INITIAL STATE
GAS
SYSTEM BOUNDARY
P
INITIAL STATE
EQUILIBRIUM STATES
QUASISTATIC
PROCESS
FINAL STATE
V

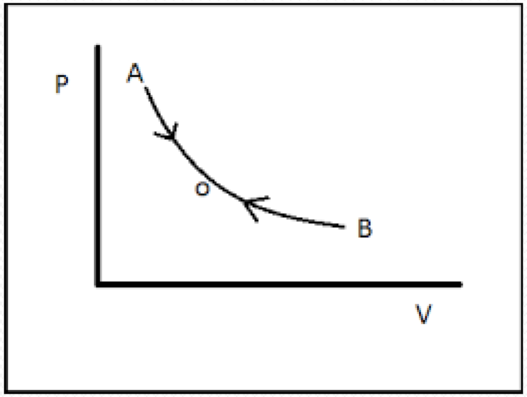
Reversible and Irreversible process

- Reversible Process and Irreversible process

- A process is said to be **reversible** if both system and surrounding can be returned back to the initial states. As shown in the fig. initially the system undergoes a change of state from state A to state B. Now if the process is reversed then path B to A will be followed, and respective initial states will be restored by the system.

- A process is said to be **Irreversible** if both system and surrounding cannot be returned back to its initial position.

Reversible Process



Temperature

- Temperature: The degree of hotness and coldness is called temperature. It is an intensive property. Thermometer is used to measure the temperature.
- The temperature scales normally employed for measurement of temperature are as follows:-
- Celsius Scale (^oC)
- Fahrenheit Scale (^oF)
- Absolute Temperature (^oK)
- Celsius Scale: These scales are based on specification of number of increments between the freezing point of water and boiling point of water at standard atmospheric pressure. Between these points Celsius scale has 100 points. In short on Celsius Scale it has 0 at freezing point and 100 at boiling point.
- Fahrenheit Scale: Fahrenheit Scale has 180 units. and in Fahrenheit scale freezing point is marked at 32 and boiling point at 212.
- The relationship between Celsius Scale and Fahrenheit Scale is given as below

$$C/100 = (F - 32)/180$$

- Absolute Temperature: The zero reading of both the above scales are chosen arbitrarily for the purpose of simplicity. If the temperature of water is below the freezing point of water, need of new scale was felt whose reference is true zero. The temperature below which the temperature of any substance cannot fall is termed as absolute temperature. For all calculations, the absolute zero temperature is taken as -273 ^oC, in case of Celsius Scale and in case of Fahrenheit Scale it is -460 ^oF. The absolute temperature in Celsius Scale is called degree Kelvin (K) and Fahrenheit Scale is called degree Rankin.
- $T\ (K) = T(C) + 273$
- $T\ (R) = T\ (F) + 273$
-

Pressure

- Pressure: Pressure is the force exerted per unit area of the surface.
- Pressure, P= F/A
- Where F is force and A is the area on which force is exerted.
- The SI units of pressure are N/m^2 . And other units of Pressure are:
- 1 bar = $1x10^5$ N/m^2
- 1 Pa(Pascal) = 1 N/m^2
- Also 1 atm. =101.325 KPa= 1.01325 bar.

volume

- Volume:- Volume is defined as the space occupied by the substance. S.I. units of Volume is m^3.
- Specific Volume:- It is reciprocal of specific weight and denoted by v. It is ratio of volume occupied by the substance per unit weight.
- Specific Weight:-It is the weight per unit volume. It is denoted by w.
- SI units of specific weight are N/ m^3.

Internal energy

- Internal Energy: It is the energy stored in the body. Every system or body requires some energy for its existence. It is the internal energy which a system stores for its existence
- Internal Energy in the substance is due to the arrangement of its molecules and molecular motion. It is denoted by U.
- When certain amount of energy is supplied to a system, a part of it gets converted into mechanical energy and remaining gets stored in the system itself. This stored energy increases the temperature of the body. It is the function of temperature.
- Internal Energy is given by
- $\Delta U = mC_v(T_2 - T_1)$

Enthalpy

- Enthalpy: It is the sum of internal energy and product of pressure and volume. It is the total energy stored in a body. It is denoted by H.
- Mathematically it is given as below
- $H = U + PV$
- And enthalpy for unit mass is given by
- $h = u + Pv$

CHAPTER- 2

- LAW OF PERFECT GASES

- PERFECT GAS
-
- An ideal gas or a perfect gas may be defined as a state of a substance, whose evaporation
- from its liquid state is complete. A perfect gas strictly obeys all the gas laws under all conditions of temperature and pressure. In actual practice, no gas is perfect gas, but some real gases like oxygen, nitrogen, hydrogen, air etc. may be regarded as perfect gases within certain temperature and pressure limits.

- LAWS OF PERFECT GASES

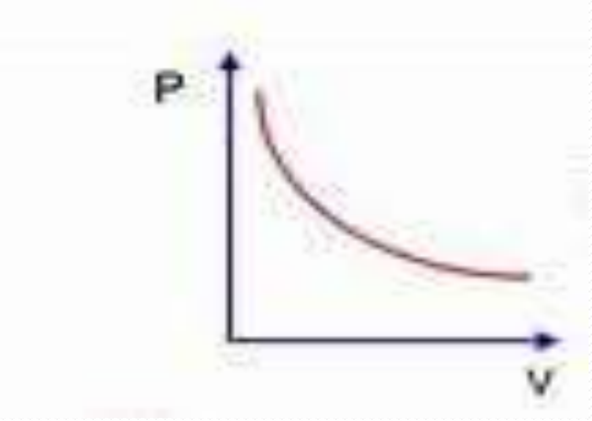
- There are mainly three variables which control the physical attributes of a gas:
- (i) Temperature of gas (T), (ii) Pressure exerted by gas (P), (iii) Volume occupied by
- gas (V)
- The behaviour of perfect gas undergoing any change in above mentioned variables is given
- by various laws which are based upon the experimental results.
- (i) Boyle's law,
- (ii) Charle's law,
- (iii) Gay-Lussac law.

BOYLE'S LAW

- Boyle's law states, "The absolute pressure of a given mass of a perfect gas varies inversely as its volume, provided the temperature remains constant."
- Mathematically,
- $$P \propto \frac{1}{V}$$
- Or PV = Constant

- The more useful form of the above equation is
- $P_1V_1=P_2V_2=P_3V_3=$ .... =constant

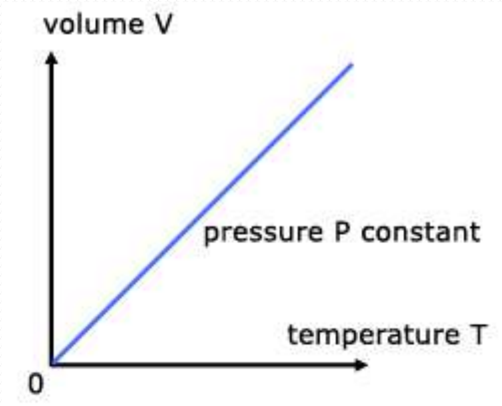
Boyle’s law



CHARLE'S LAW

- This law may be stated in the following two ways:
- (i) "The volume of a given mass of a perfect gas varies directly as its absolute temperature, provided the pressure remains constant." Mathematically,
- $V \propto T$ or $V/T =$ constant
- or $V_1/T_1 = V_2/T_2 = V_3/T_3 = \ldots\ldots\ldots\ldots\ldots\ldots = \text{constant}$
-
- (ii) "All perfect gases change in volume by 1/273th of its original volume at 0°C for every 1°C change in temperature, when the pressure remains constant."

Charles law



AVOGADRO'S LAW

- It states, "Equal volume of all gases will have equal number of molecules, under identical conditions of temperature and pressure."
-
- According to this law, 1 m^3 of hydrogen will contain the same number of molecules as 1 m^3 of oxygen when temperature and pressure is same. We know that molecular mass of hydrogen is 2 and that of oxygen is 32. As 1m^3 of these two gases have equal number of molecules, therefore, mass of one molecule of oxygen will be32/2= 16 times the mass of hydrogen molecule. In other words, the density of oxygen is 16 times the density of hydrogen. Hence Avogadro's law indicates that the density of any two gases is directly proportional to their molecular masses at the same temperature and pressure.

- At normal temperature and pressure (N.T.P.) i.e. at 0°C and 1.01325 bar, the density of oxygen is 1.429 kg/m3
- Specific volume of oxygen at N.T.P., V = 1/1.429 m3/kg
-
- Volume of 32 kg (or 1 kg-mol) of oxygen at N.T.P = 1/1.429 x 32= 22.4m3
-
- In this way, it can be proved that volume of 1 kg mol of any gas at N.T.P is 22.4 m3.
-

REGNAULT'S LAW

- This law states, "The two specific heats Cp (specific heat at constant pressure) and Cv (specific heat at constant volume) of a gas do not change with the change of temperature and pressure."
- As the specific heats of a gas vary with the temperatures, therefore, Regnault's law gives the approximate results only. The variation in the results can be as high as 20% in engineering practice due to variation in specific heat with the increase in temperature.
-

$R_u = MR$

UNIVERSAL GAS CONSTANT

- The universal gas costant or molar constant (generally denoted by Ru) of a gas is the product of the gas constant and the molecular mass of gas.
- Ru=8314 j/kg/k

SPECIFIC HEAT

- It may be defined as the amount of heat required to raise the temperature of its unit mass through one degree. All the liquids and solids have only one specific heat while a gas has mainly two types of specific heats.
- Specific Heat At Constant Pressure :-
- It is the amount of heat required to raise the temperature of a unit mass of a gas through one degree, when its pressure is kept constant.
- If m kg of a gas is heated from temperature T1 to temperature T2 at constant pressure, then amount of heat supplied to gas is given by

$$Q = m\, c_p \Delta T$$

- The value of c_p for air in S.I. unit is 1 kJ/kg K.

Specific Heat At Constant Volume (Cv)

- It is the amount of heat required to raise the temperature of a unit mass of a gas through
- degree, when its volume is kept constant.
- If m kg of a gas is heated at constant volume from temperature T1, to temperature T2, then
- amount of heat supplied to gas is given by
- $$Q = m\, c_v\, \Delta T$$
- The value of c_v for air in S.I. unit is 0.72 kJ/kg K

CHATER -3

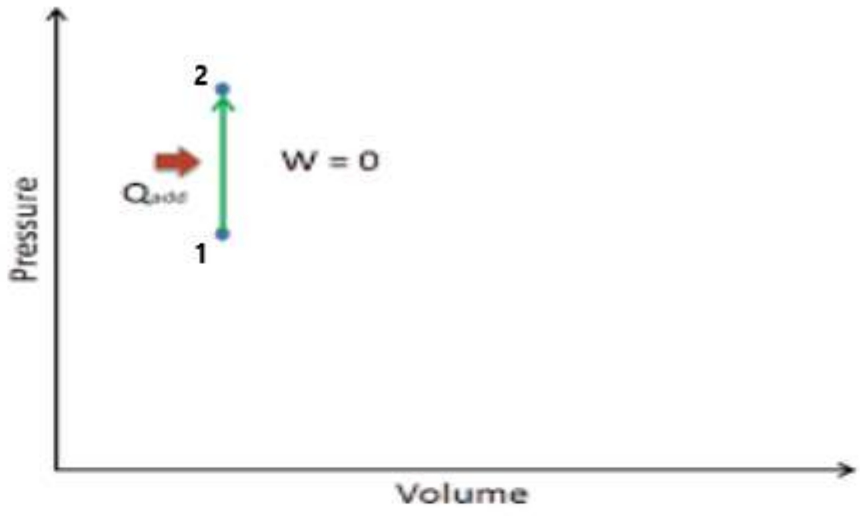
- THERMODYNAMICS PROCESSES

Thermodynamic process

- A thermodynamic process is the change in the state of gas as a result of energy. The change in one or more properties takes place during the process as a result of flow of energy. The properties are pressure, volume, temperatue,internal energy ,heat and work.
- The following are types of thermodynamic processes.
- Isochoric process
- Isobaricprocess
- Isothermal process
- adiabatic process
- Isentropic process
- Polytropic process
- Throttling process

Isochoric or constant volume process

- A process in which volume of the given mass of the gas remains constant befire and after heating is known as isochoric or constant volume process.
- Due to heating of given mass m of gas, pressure and temperature will rise. As volume is constant so no work will be done by gas. In diagram point 1 represents the state of the gas before heating and point 2 represents the state of gas after heating.



2
W = 0
Pressure
1
Volume

- Work done

$$W_{1-2}=\int_1^2 P\ dV=P(V_2-V_1)$$

as $dV=0$

So $W_{1-2}=0$

- Heat transferred

$$Q_{1-2}=\int_1^2 mC_v\,dT= mC_v\,(T_2-T_1)$$

- change In internal energy
- According to first law of thermodynamics

$Q_{12}= \Delta U_{1-2}+W_{1-2}$

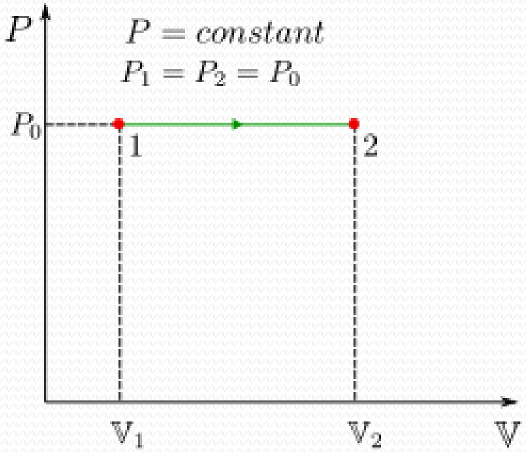
As $W_{1-2}=0$

So $Q_{1-2}= \Delta U_{1-2}$

- Heat transferred = change in internal energy

Isobaric or constant pressure process

- A process in which pressureof the given mass of the gas remains constant before and after heating is known as isobaric or constant presssure process.
- Due to heating of the given mass m of the gas the volume and temperature will rise .



Isobaric Process

Work done

$W_{1-2} = \int_1^2 PdV = P(V_2 - V_1)$

Heat transferred

$Q_{1-2} = \int_1^2 mC_p dT = mC_p(T_2 - T_1)$

change in Internal energy

$\Delta U_{1-2} = mC_v(T_2 - T_1)$

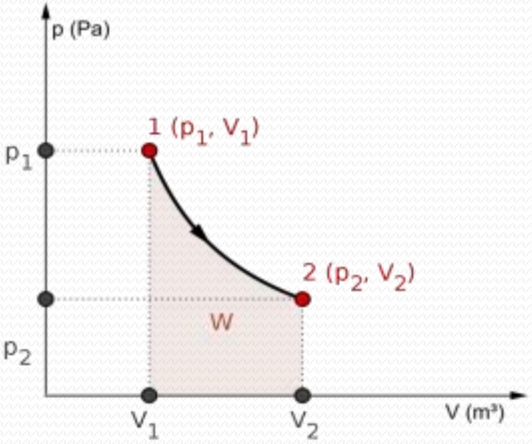
Change in enthalpy

$\Delta H_{1-2} = mC_p(T_2 - T_1)$

Isothermal process or constant temperature process

- A process in which temperature of a given mass of a gas remains constant when heat is a supplied to the gas is known as isothermal or constant temperature process.

Isothermal process



According to first law of thermodynamics

$Q_{1-2} = \Delta U_{1-2} + W_{1-2}$

as $T_1 = T_2$

$\Delta U_{1-2} = m\, C_v (T_2 - T_1) = 0$

Work done

$$W_{1-2} = \int_1^2 P\, dV = \int_1^2 PV\, dV/V = PV \log(V_2/V_1), \text{ as } PV = P_1V_1 = P_2V_2$$

So , $= P_1V_1 \log(V_2/V_1)$

Heat trasnsferred

$Q_{1-2} = W_{1-2} = P_1V_1 \log(V_2/V_1)$

Adiabatic process

- The process in which no heat is added or withdrawn from the system under consideration is known as adiabatic process.
- In this process there is no heat transfer between system and surroundings when work is done by the gas or on the gas.

1. Work done

$W_{1-2} = (P_1V_1 - P_2V_2)/ \Upsilon - 1$

2.Heat transferred

$Q_{1-2} = 0$

3.change in Internal energy

$\Delta U_{1-2} = mC_v (T_2 - T_1)$

4.Change in entropy=0

Change in enthalpy

5. $\Delta H = mC_p (T_2 - T_1)$

Polytropic process

The process which follows general relationship PV^n=Constant is known as polytropic process.

1. Work done

W_{1-2}= ($P_1V_1-P_2V_2$)/ n-1

2. Heat transferred

Q_{1-2}= Υ-n/Υ-1* W_{1-2}

3. change in Internal energy

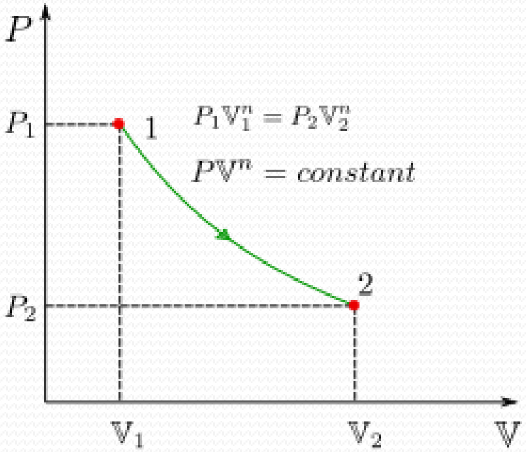
$\Delta U_{1-2}=mC_v (T_2-T_1)$

4. Change in enthalpy

$\Delta H= mC_p (T_2-T_1)$

5. change in entropy

S_2-S_1= mC_v(n-Υ/n-1)logT_2/T_1



Polytropic Process

Throttling process

- When a gas or vapour is expanded through an aperture of mixture dimension like a valve , which is very slightly opened ,the process is known as throttling process.
- During throttling process no heat is supplied or rejected, no external work is done and in case of perfect gas there is no change in temperature.
- $W = 0$
- $Q = 0$
- $\Delta U = 0$

Chapter-4

- LAWS OF THERMODYNAMICS

Law of conservation of energy

- It states that energy can neither created not destroyed but can be converted from one form to another. This means that the total energy possessed by a body remains constant.
- Example:-conversion of water energy into heat energy during power generation in hydroelectric power plant.

First law of thermodynamics

- According to this law, Heat and mechanical work are inter-convertible.
- The second form of first law comes out of the extension of the law of conservation of energy. It is stated that ,in all transformations, the energy due to heat units supplied must be balanced by gain in internal energy plus by the external work done due to rise in temperature.
- $dQ = dU + dW$

APPLICATION OF FIRST LAW OF THERMODYNAMICS TO NON FLOW SYSTEMS

- Reversible non flow processes:-

- Constant volume process
- Constant pressure process
- Adiabatic process
- Polytropic process

Steady flow energy equation

- Steady flow energy equation is used for open systems to determine the total energy flows. Consider a open system in which working substance flows at steady rate.

- m= mass of working substance
- P_1,P_2= pressure at inlet and outlet
- V_1,V_2= Volume at inlet and outlet
- Q=heat supplied
- W= work done
- C_1,C_2= velocity at inlet and outlet
- U_1,U_2 = internal energy at inlet and outlet
- Z_1,Z_2= datum height at inlet and outlet

- According to law of conservation of energy
- Energy at entrance = Energy at exit
- $m(C_1^2/2 + gZ_1 + U_1 + P_1V_1) + Q = m(C_2^2/2 + gZ_2 + U_2 + P_2V_2) + W$
- as $H = U + PV$
- So, $m(C_1^2/2 + Z_1g + H_1) = m(C_2^2/2 + Z_2g + H_2) + W$
- This equation is steady flow energy equation.

Applications of steady flow enegy equation

- Turbine:- a turbine is a device which converts fluid energy into mechanical work. there is no transfer of heat.
- Q=0, put in steady flow energy equation
- $m(C_1^2/2 + Z_1 g + H_1) = m(C_2^2/2 + Z_2 g + H_2) + W$

- Kinetic and potential energies are neglected.
- So, $H_1 = H_{2+} W$ or $W = H_1 - H_2$

- Pump
- A pump is device which lifts the water from lower level and delivers it to higher level. In pump Q=0 , $\Delta U=0$ and work is done on the system, so it is negative.
- Steady flow energy equation becomes
- $m(C_1^2/2 + gZ_1 + P_1V_1) = m(C_2^2/2 + gZ_2 + P_2V_2) - W$

- Evaporator:-it is commonly used in refrigerating units. Heat is taken from the surroundings and utilized to evaporate the refrigerant. Work done is zero, kinetic energy and potential energy can be neglected. Now steady flow energy eq. becomes:-
- $Q = H_2 - H_1$

- Boiler
- Boiler is a device which is used to generate the steam after heating the water. In boiler W=0,kinetic and energy are neglected.
- From steady flow energy equation
- $Q= H_2 - H_1$
- Compressor :- compressor is used to increase pressure of air. Work is done on compressor. Work done is negative. Heat is lost from system, therefore Q is negative
- $mH_1 -Q= mH_2+W$
- or $W=Q+ m(H_2- H_1)$
-

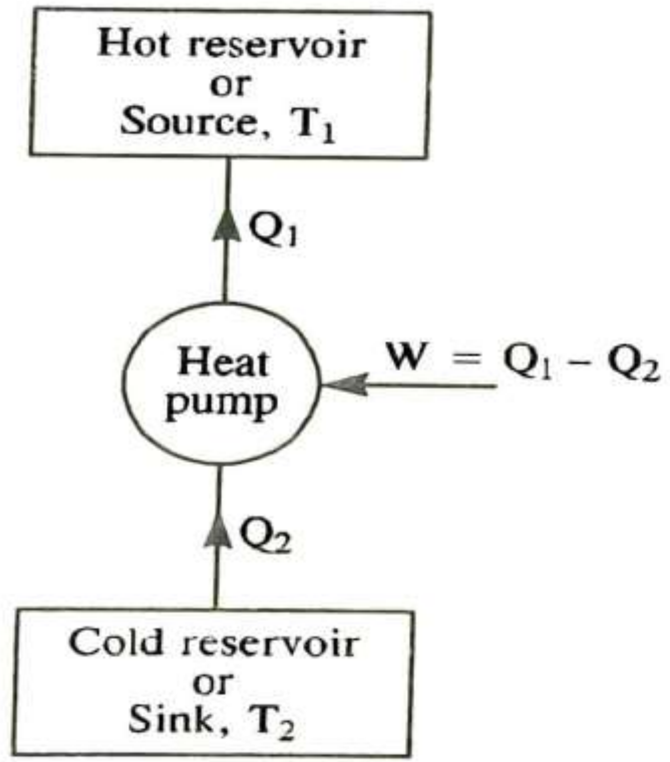
- Nozzle:- a nozzle is a device to increase the velocity of the fluid. In nozzle work done is zero. W=0 , Q=0
-
- $m(C_1^2/2 + H_1) = m(C_2^2/2 + H_2)$
- $C_1^2/2 + H_1 = C_2^2/2 + H_2$
- $H_1 - H_2 = C_2^2/2$ (C1 is very small, hence may be neglected)
- $C_2 = \sqrt{2(H1 - H2)}$

- Heat source:- The reservoir which is at high temperature and supplies heat is called heat source. Example:-combustion chamber, furnace etc.
- Heat sink:- The reservoir which is at low temperature and to which heat is transferred is called heat sink. Example:- river , atmosphere etc.

Clausius statement

- Heat flows from a hot body to a cold body unaided but it cannot flow from a cold body to a hot body without the aid of external work.

Clausius statement



Kelvin-plank statement

- It is impossible to construct an engine working on cyclic process whose sole purpose is to convert all heat energy supplied to it an equivalent amount of mechanical work.
- In other words, no actual engine in cylic process can convert all heat enrgy supplied to it into mechanical work.Some of heat energy must be lost to the surroundings.

Perpetual motion Machine of first kind

- According to one of the statements of first law of thermodynamics no machine can produce work without expenditure of energy. But a perpetual machine of the first kind is defined as machine which will give continuous work without receiving any energy from other systems . Such a machine creates its own energy and thus violates first law of thermodynamics. Therefore, first law of thermodynamics may also be stated as it is impossible to construct a perpetual machine of the first kind.

Perpetual motion Machine of second kind

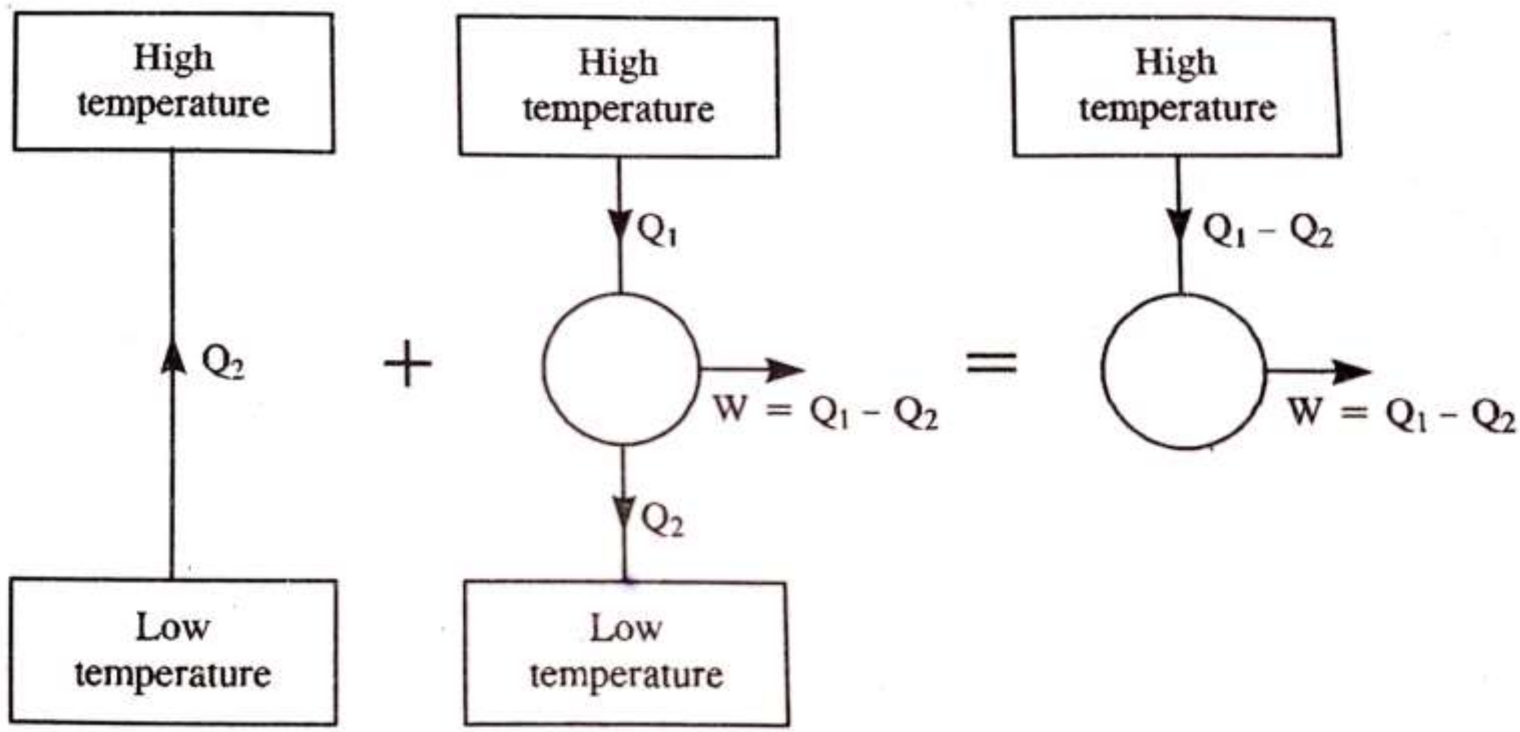
- Perpetual motion Machine of second kind

- According to second law of thermodynamics no machine can convert whole of heat energy into work and a part of energy must be rejected to a system or surroundings. But a perpetual machine of the second kind is defined as machine which converts whole of heat energy into work. It is impossible to obtain a machine in actual practice.

Equivalence of Kelvin plank and clausius statements

- The equivalence of Kelvin plank and clausius statements can be proved if a device violates Kelvin plank statement, then it also violates clausius statement and vice versa.
- Consider a heat pump which transfer heat from a low temperature reservoir to a high temperature reservoir without any external work.This violates the clausius statement.

Equivalence of Kelvin plank and clausius statements

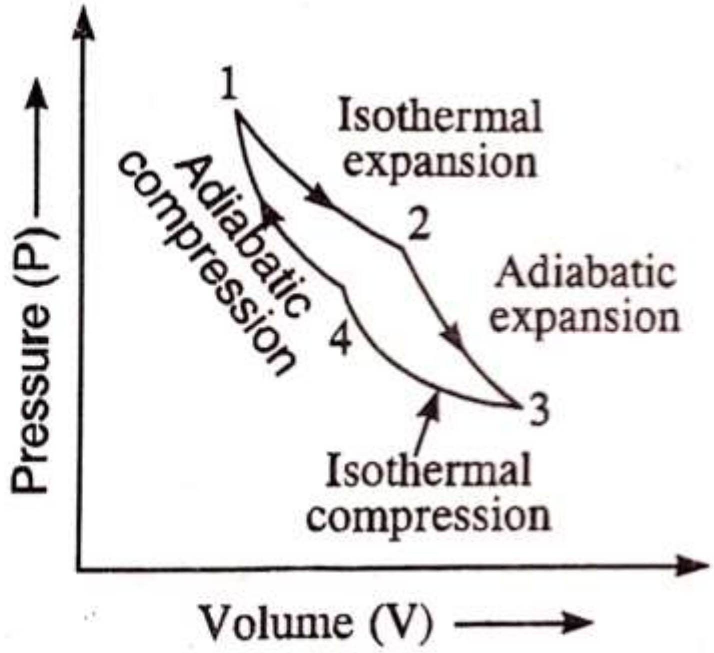


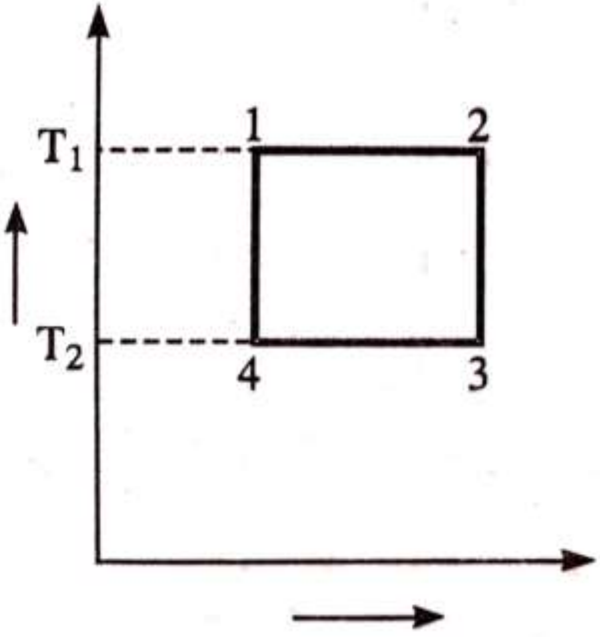
- Now consider a heat engine which takes amount of heatQ_1 from a high temperature reservoir and rejects an amount of heat Q_2 to a low temperature reservoir so work is done, $W=Q_1-Q_2$
- As there is no heat transfer to lower temperature reservoir. They together may be considered as a device that operates in a cycle exchanging heat from a high temperature reservoir and producing no effect other than work. This is violation of Kelvin plank and statement. Thus the violation of clausius statement implies violation of Kelvin plank statement.

Carnot engine

- Carnot engine :- This engine operates on carnot cycle. It comprises of two ideal reversible isothermal and two reversible adiabatic processes.
- 1. process 1-2(isothermal expansion):-heat is supplied at constant temperature T_1 during this process and is equal to work done.
- 2. process 2-3(adiabatic expansion):_air is allowed to expand adiabatically . work is done at cost of internal energy.
- 3. process 3-4(isothermal compression):-air is compressed isothermally. The heat is rejected by the air to the sink.

Carnot cycle P-V and T-S diagram





- 4. process 4-1(adiabatic compression):-the system returns back to initial state by adiabatic compression.
- Work done= heat supplied –heat rejected
- $= mRT_1 logr - mRT_2 logr = mR(T_1 - T_2) logr$
- Efficiency =work done/heat supplied= $mR(T_1-T_2)logr / mRT_1 logr$
- $= (T_1 - T_2)/ T_1$

- Concept of Irreversibility:-
- An irreversible process is one in which heat is transferred through a finite temperature. Once the process is over, it cannot come back to the original state.
- Examples:-relative motion with friction, throttling, combustion, free expansion etc.
- Third law of thermodynamics:-
- It states that the entropy of a pure substance of absolute zero temperature is zero.

- Entropy
- Entropy Is defined as a function of a quantity of heat which shows the possibility of conversion of that heat into work. the increase in entropy is small when heat is added at a high temperature and is greater when heat added at low temperature. Thus for maximum entropy there is maximum availability of heat for conversion into work.

Chapter-5

- Ideal and real gases

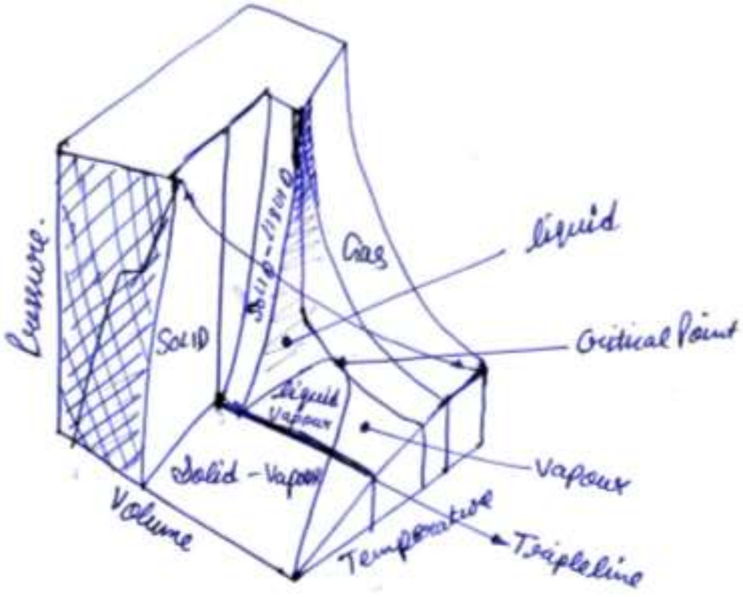
Ideal gas

- A hypothetical gas which obeys the law $PV=RT$ at all ranges of pressure and temperature is called an ideal gas.
- Enthalpy of an ideal gas
- $H=U+PV$
- For unit mass, $h= u+Pv$
- For an ideal gas
- $Pv =RT$
- So, $h=u+ (RT)_{ideal}$

since for an ideal gas u it is a function old temperature, so it follows that enthalpy is also a function of temperature alone.

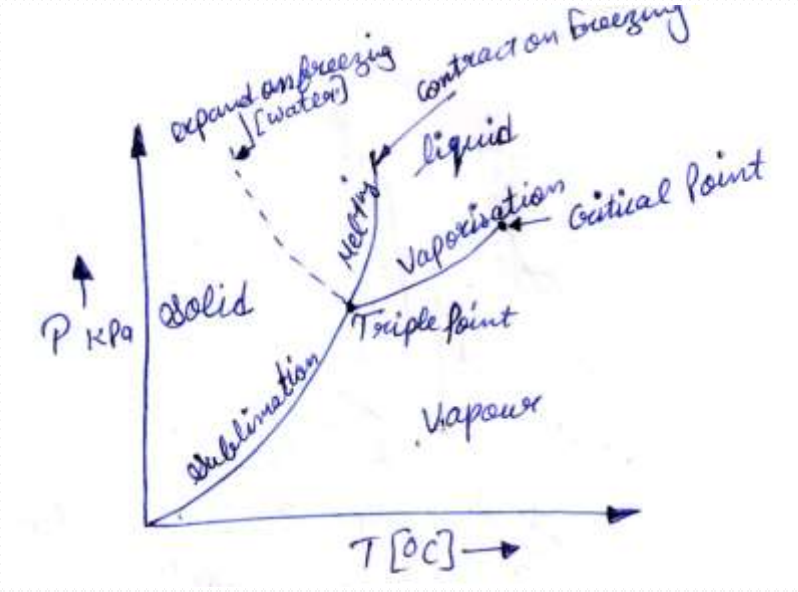
P-V-T surface of an ideal gas

- The equation of state for an ideal gas is a relation between the three variables, pressure, volume and temperature. This relationship is shown graphically by using pressure, temperature and volume as coordinates in three mutually perpendiculars planes. The portion of a figure in which space which represents P-V-T relationship for an ideal gas is known as P-V-T surface.
- A P – V diagram is just a Projection of the P – V – T surface on the P – V Plane. Similarly, a T – V diagram is nothing more than the birds eye view of this surface. Note that the P – V – T surface Provide a good amount of information.
- In a Thermodynamic analysis, it is comparatively easier to work with two dimensional diagrams, such as the P – V and T – V diagrams.


Pressure.
Solid
Gas
liquid
Critical Point
Liquid Vapour
Vapour
Solid - Vapour
Volume
Temperature
Tripleline

Triple point

- Triple point of a substance is at which all the three phases, solids, liquids and gases co-exists in thermodynamic equilibrium. The triple point exists at a definite pressure and temperature



expand on freezing [water]
contraction on freezing
liquid
Melting
Vaporisation
Critical Point
Solid
P KPa
Triple Point
Sublimation
Vapour
T [°C]

Real gases

- A real gas is a gas that does not behaves like an ideal gas due to interactions between gas molecules.
- Any gas which does not obey the gas law PV=RT and if it obeys this law , it obeys at very low temperature and pressure.
- Experiments shows that most of the real gases obey boyle's and charles laws quite closely, at relatively low temperatures and pressures. In practice, all gases are only real gases. .To understand the behavior of real gases.
- This must be taken into account :-
- Compressibility effects.
- Variable specific heat capacity
- Vander waals Forces,
- Non-equilibrium thermodynamic effects
- Issues with molecular dissociation and elementary reactions with variable composition. Properties of a Real Gas :-
- The specific heats varies with pressure and temperature.
- The enthalpy and internal energy are the function of pressure and temperature.
- The entropy equation Pertaining to ideal gas will not be valid for the real .

VANDER WAALS EQUATION

Vander waal's equation for real gas is written as:

$(P+a/v^2)(v-b)=RT$

the constants a and b are specific constants, v represents the volume per nit mass and R is the gas constant. If the volume of one mole of gas is considered, then Vander waal's equation can be written as follows:

$(P+a/v^2)(v-b)=RuT$

Units

V is in m^3/kg mole, P inN/m^2

T in kelvin Ru is 8314j/kg k

a in Nm^4 /kg ,b in m^3/kg mol

Chapter 6

Properties of steam

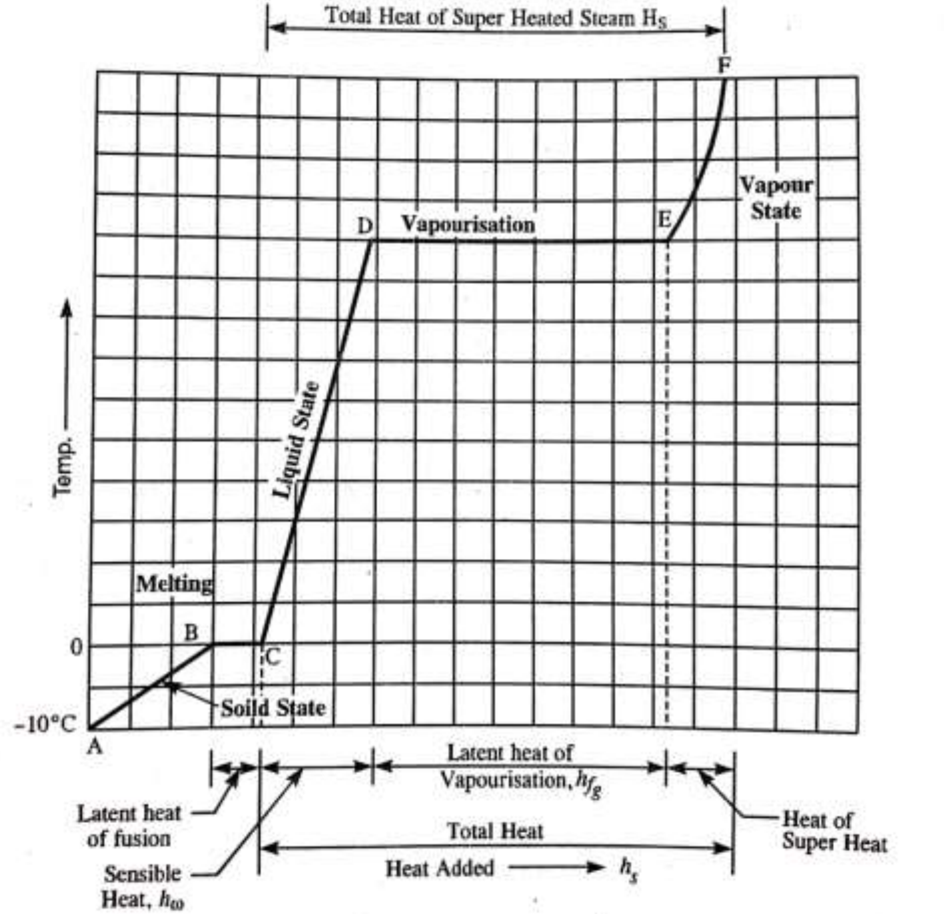
INTRODUCTION

- Steam is a water vapour and is invisible when it is pure and dry. It is different from gas, as gas is in gaseous state at room temperature but steam is in liquid state at room temperature. It does not follow the laws of perfect gases until it is perfectly dry.

Formation of steam

- Consider the initial temperature of ice is a solid phase of water is -10^{o}c. keep pressure constant , we provide continous heat to the ice.
- 1. At point A at which ice is at temperature -10^{o}c .the heat given to ice , its temperature rises., upto point B.
- 2.At point B the phase transformation of solid ice into liquid takes place, there is no rise in temperature.
- 3. The temperature of water increases on heating from 0^{o}c to 100^{o}c. During the process C-D ,sensible heat of water is absorbed.
- 4.On further heating at point D , the water gradually turns into steam ,there is no rise in temperature. The heat added during process D-E is called latent heat of vapourisation of steam.
- 5.On further heating at constant pressure at point E before the process E-F, the steam so obtained is called super heated steam, it behaves like a perfect gas.

Formation of steam



Types of steam

- **WET STEAM :** When the steam contains particles moisture in suspension, it is called wet steam.
- **DRY SATURATED STEAM:** When the wet steam is heated further and it does not contain any suspended water particles, it is called dry saturated steam.
- **SUPERHEATED STEAM** : If the heat is added further to dry steam its temperature increases, while pressure remains constant, called superheated steam.

- **LATENT HEAT OF STEAM:** It is defined as the quantity of heat required to convert one kg of water to dry saturated steam at same pressure.

- **TOTAL HEAT OR ENTAHLPY OF STEAM:** It is the total amount of heat absorbed by water from freezing point to saturation temperature plus the heat absorbed during evaporation.

- **DRYNESS FRACTION**: It is the ratio of mass of actual dry steam to mass of same quantity of wet steam. It is denoted by x.

- **WETNESS FRACTION**: It is the ratio of mass of water vapour to mass of same quantity of wet steam. It is denoted by y.

- **SPECIFIC VOLUME OF STEAM**: It is the volume occupied by the steam per unit mass at given temperature. It is the reciprocal of density of steam.

- **INTERNAL LATENT HEAT**
- The difference between the latent heat and external work done during evaporation is known as internal latent heat.
- **INTERNAL ENERGY OF STEAM:**
- The heat energy stored in the steam above the freezing point of water is called internal energy of steam. It is denoted by u
- **ENTROPY OF WATER =**
- It Is the degree of randomness. If water is heated from absolute temperature T_o to T K, then the change in entropy per kg of water at constant pressure is given by:
- = specific heat of water $\times \log_e T/T_o$
- **ENTROPY OF EVAPORATION =**
- Change in entropy = q/t
- Change in entropy during evaporation = h_{fg}/T

- **HYPERBOLIC PROCESS**—The process $Pv =$ constant is known as hyperbolic process. A process in which the gas is heated in such a way that the product of its pressure and volume is constant .This process is governed by Boyle's law.

  V_1 and V_2 are the specific volumes of steam, applying first law of thermodynamics:

$$q = (h_2 - h_1) + P_1 v_1 \log_e (v_2/v_1)$$

- **THROLLTING PROCESS:** It is a process in which there is no change in enthalpy from one state to state two. An ideal gas flowing through a valve in mid position is example of throttling process.

- **REVERSIBLE ADIABATIC PROCESS** : The adiabatic process may be reversible or irreversible . The reversible adiabatic process is known as isentropic process or constant entropy process. But when there is some friction involved in this process , it is then, known as irreversible adiabatic process.
- We know that:
- 1.There is no transfer of heat through the cylinder walls.

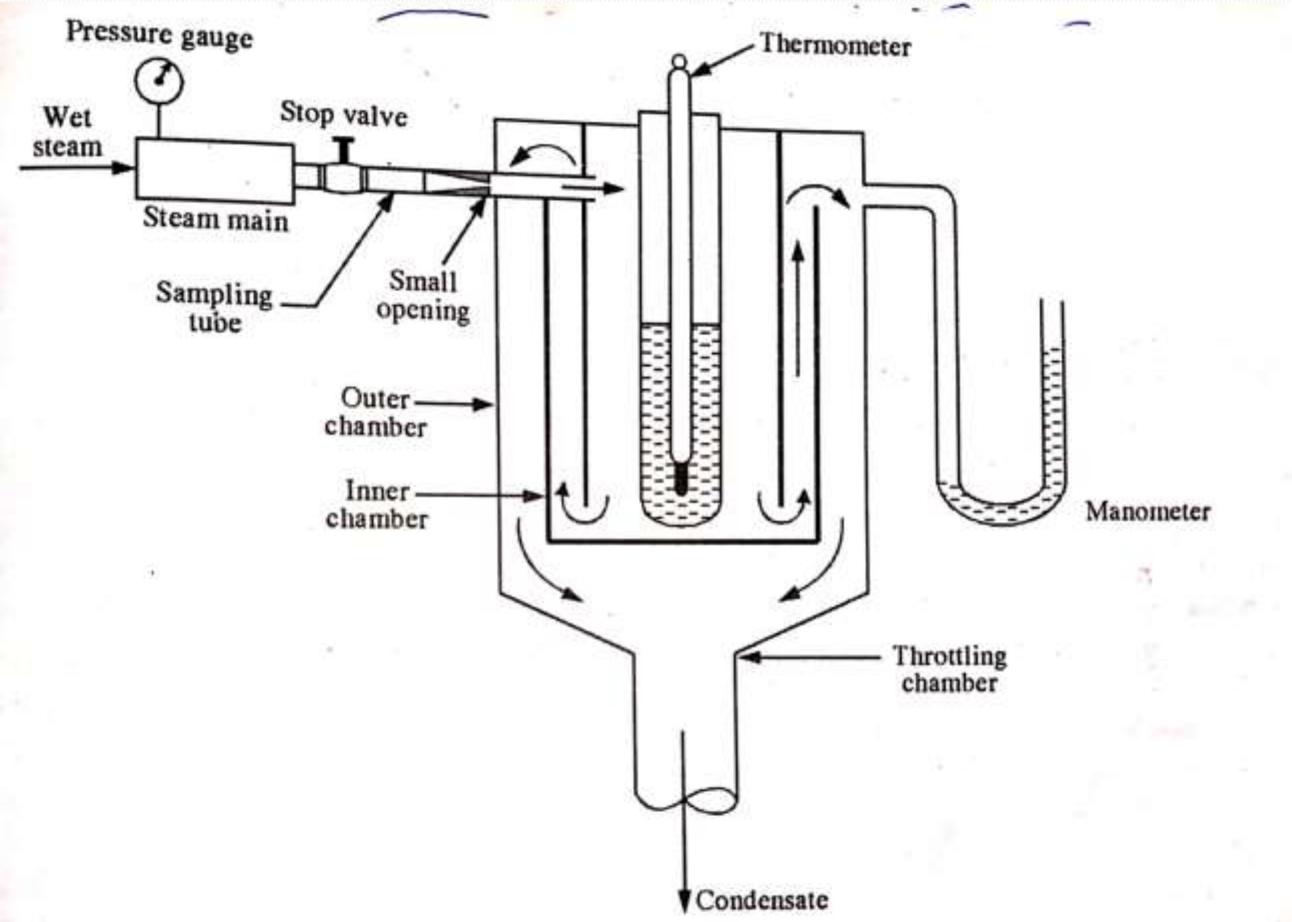
  2. There is no change in entropy.
  3. The work is done on the piston by expanding the steam.
- An adiabatic process occurs without transfer of heat or mass of substance between a thermodynamic system and its surroundings. In this energy is transferred to surrounding only as work .
- Many engineering devices such as pumps, turbines , nozzles are adiabatic in nature

- **DETERMINATION OF QUALITY OF STEAM (DRYNESS FRACTION) :**
-
- To define the state of pure substance, two independent properties are needed. There may be pressure and temperature.
- Steam quality is a mixture of the amount of saturated steam that coexists with its condensate in a given system. Dryness fraction is the ratio of mass of actual dry steam to the mass of same quantity of wet steam. It is generally denoted by x. Mathematically ,
- $x = m_g/m_g+m_f = =m_g / m$
- where, m_g = mass of actual dry steam
- m_f = mass of water in suspension
- $m =$ mass of wet steam $= m_g + m_f$
- Since , it is relatively difficult to measure the specific volume of mixture , devices such as calorimeters are used for determining the quality of the mixture. In the measurement of quality, the objective is always to bring the state of the substance from to phase region (L+V) to single phase region i.e. gas region or superheated region, where both pressure and temperature are independent. The temperature and pressure are measured to fix the state. The purpose is fulfilled by adiabatic throttling or electric heating.

- **Measurement of quality using separating calorimeter:**
- **WORKING:** It consists of two concentric chambers, the inner chamber and the outer chamber, which communicates with each other through an opening at the top. As the steam discharges through the metal basket, which has a large number of holes, the water particles due to their heavier momentum get separated from the steam and collect in the chamber. The comparatively dry steam in the inner chamber moves up and then moves through the annular space between the two chambers. The dry saturated steam is then passed through a check valve to get condensed in the condenser. The water formed is collected in a container.

- **2 . MEASUREMENT OF QUALITY USING THROTTLING CALORIMETER:**
- **WORKING:** It consists a narrow throat (Orifice). Pressure and temperature are measured by pressure gauge and thermometer. The steam is passed through a throttle valve and the throttled steam flows into the inner chamber. For better results ,the steam should be in a superheated state after throttling. The steam then flowing out of inner chamber moves up and then moves downwards into the annular space between the two chambers and then exhausted to atmosphere.

Throttling calorimeter



Chapter 7

Steam generators

Uses of Steam

- Water and steam are typically used as heat carriers in heating system.
- Power generation
- Heating the residential and commercial buildings in cold weather countries.
- sugar industries and chemical industries etc.
- Steam turbines of power plants for power generation.

- **Boiler:** Boiler is a equipment used for producing and transferring steam is called steam generator/ boiler. Boilers are broadly classified as:
- **1. Horizontal, Vertical or Inclined Boiler.**
  If the axis of the boiler is horizontal, the boiler is called horizontal.
- If the axis is vertical, it is called vertical boiler.
- If the axis is inclined, it is called as inclined boiler.
- **2. Fire Tube and Water Tube**
- In the fire boilers, the hot gases are inside the tubes and the water surrounds the tubes. e.g. Cochran, Lancashire and Locomotive boilers.
- In the water tube boilers, the water is inside the tubes and hot gases surrounds the tubes . e.g. Babcock and Wilcox etc.
- **3. Externally fired and internally fired**
  The boiler is known as externally fired if the fire is outside the shell. e.g. Babcock and Wilcox boiler
  In case of internally fired boilers, the furnace is located inside the shell. e.g. Cochran, Lancashire boiler etc.
- **4. Forced circulation and Natural Circulation**
- In forced circulation type of boilers, the circulation of water is done by a forced pump. e.g. Lamont, Benson Boiler etc.
- In natural circulation type of boilers, circulation of water in the boiler takes place due to natural convention currents produced by the application of heat. e.g. Lancashire, Babcock and Wilcox boiler etc.

- **5. Higher Pressure and Low Pressure Boilers**
  The boiler which produce steam at pressures of 80 bar and above are called high pressure boilers. e.g. Babcock and Wilcox, Benson Boiler etc.
- The boilers which produce steam at pressure below 80 bar are called low pressure boilers. e.g. Cochran, Cornish, Lancashire and Locomotive boiler etc.
- **6. Stationary and Portable**
  Stationary boilers are used for power plant steam, for central station utility power plants, for plant process steam etc.
  Mobile boilers or portable boilers include locomotive type, and other small units for temporary use at sites.
- **7. Single Tube and Multi Tube Boiler**
  The fire tube boilers are classified depending upon whether the fire tube is one or more than one. These are:
- (i) Single tube boilers e.g. Cornish, simple vertical boiler
- (ii) Multi-tube boilers e.g. rest of the boilers

8. According to passes
(i) Single pass
(ii) Multi pass

Comparison between Water Tube and Fire Tube Boilers

WATER TUBE

- Water passes through water tubes.
- Requires more floor area
- Complexity in design requires quick examination by skilled hands.
- Operating pressure up to 200 bar.
- Evaporation rate ranges from 20,000 to 50,000kg/hr.
- Externally fired boilers, furnace size can be varied.
- Low water to steam ratio.
- Bigger in size, suitable for large power plants
- Transportation and installation is easy due to handling of dismantled parts.

FIRE TUBE

- Hot gases passes through tubes.
- Requires less floor area
- Simple & rigid construction hence greater reliability & low operating cost.
- Pressure ranges from 17.5 bar to 24.5 bar
- Evaporation rate 900kg/hr.
- Internally fired boilers, furnace size can not be varied.
- Large water to steam ratio.
- Smaller in size, used only for small power plants
- Transportation and installation is difficult due to large size of shell.

- **Functions of Various Boiler Mountings**
- The essential devices installed for the proper functioning of a boiler are called boiler mountings. e.g. steam stop valve, fusible plug, blow off cock, pressure gauge, safety valve, water level indicator, feed check valve, mud hole and man hole. In accordance with the Indian boiler regulations the following mountings should be fitted to boilers.
- **1. Safety valves:** The function of the valve is to blow off the steam when the pressure of the steam in the boiler exceeds the working pressure.
- **2. Water level Indicator:** Its function is to indicate level of water, its upper end open in steam space and lower end opens to water space.
- **3. Pressure gauge:** It is for indicating the pressure of steam in a boiler.

- **4. Steam stop valve:** It stops or allows the flow of steam from the boiler to the steam pipe.
- **5. Feed check valve:** It allows or stops the supply of water to the boiler.
- **6. Blow off cock:** It is for removal of sediment periodically collected at the bottom of the boiler.
- **7. Man hole:** It is provided in opening from which a man can enter in a boiler for cleaning.
- **8. Fusible plug:** It is safety device used in the boiler to prevent the damage to the boiler due to over heating ,when water level is very low.

Functions of Various Boiler Accessories

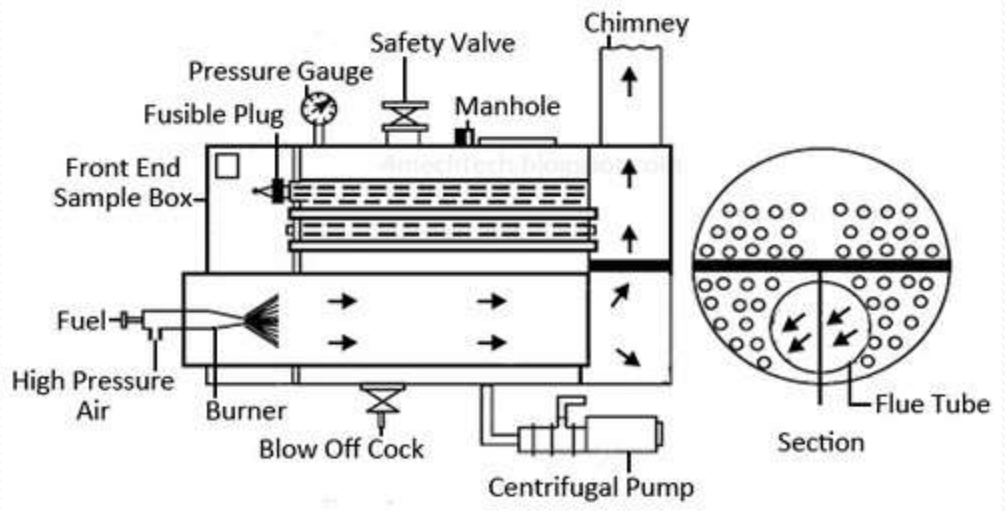
- The devices which are installed in the boiler for their efficient operation are called boiler accessories. e.g. air pre-heater, economiser, super heater.
- **1. Economizers:** An economiser is placed in the path of the flue gases to pre heat the feed water. The hot gases passover the external surface of water tubes.
- **Advantages:** Fuel economy and Long life of the boiler

- **2. Air pre-heaters:** Air pre-heaters is installed between the economizer and the chimney and it abstracts heat from the flue gases and transfers to air before it enters the combustion chamber.
- **3. Super heaters:** the function of super heater is to convert dry saturated steam into superheated steam. It is placed in the path of the hot flue gases.
- **4. Feed pumps:** It is used to pump the water from storage to boiler.
- **5. Injectors:** It is also used to pump the water to the boiler. It is used in vertical and locomotive boilers and small capacity boilers.

Nestler Boiler

- This is a package type fire tube boiler having working pressure of about 12 bar. the fuel used in this boiler is furnace oil which is a thick dark coloured fluid of very high viscosity. The oil is heated to about 50°C by a high wattage electric heater before it is supplied to the burner. the burner injects the oil into the furnace tube with the help of high pressure blast of air supplied by a blower.
- **Construction and Working**
- The boiler shell consists of 12 mm thick mild steel plate and is welded with two plates one at each end. a large number of fire tubes of 50 mm diameter each are fitted between the two end plates in addition to 0.5m diameter furnace tube which extends from the front end plate to the rear end plate. The burner is provided at the mid of the furnace tube. at each end of the boiler shell, there is a smoke box.

Nestler boiler

- 

- In the rear end of smoke box, a deflection arch is provided to divert the flow of flue gases. The flue gases first traverse through the entire length of the furnace tube upto the rear end where they enter the smoke box. thereafter, they enter lower set of small diameter fire tubes and travel all along through these tubes upto the front end smoke box from where they rise up and get into the upper set of fire tubes. The flue gases are finally discharged into the atmosphere through chimney. The flue gases thus traverse the entire length of the boiler three times so as to provide their heat to water to the maximum extent. the steam produced is collected in the steam space and may be taken out through the stop valve. the front end fire box is provided with two explosion doors.

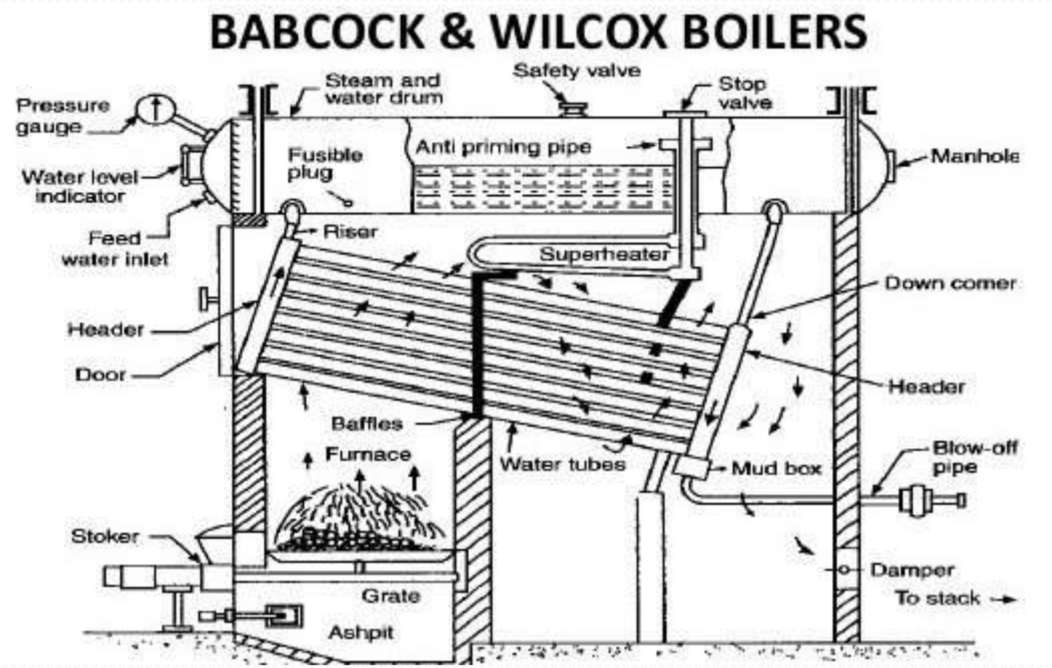
Lancashire Boiler

- Pump the water into the boiler shell through the economizer with the help of a non-return feed valve till the fire tubes submerge in it. The fuel is charged through the fire holes on to the grate and burnt. The hot gases travel upto the back end of the fire tubes transferring about 83% of the total heat to the water. Then they travel in the downward direction through the bottom flue to the front of the boiler transferring about 9.5% of total heat, where they are divided into two streams and travel through the side flues transferring the remaining 7.5% of the total heat before reaching the chimney. The path of hot gases are shown by arrows in the figure. The flow of gases controlled by dampers, which regulates the rate of combustion as well as steam generation. The mud and sediments formed in the shell removed using the blow-off cock.

- The steam is accumulated in the steam space above the water level, is passed over an antipriming pipe A, to flow through a super heater K. The hot gases before entering the bottom. flue passed over the super heater. The superheated steam is finally drawn through steam stop valve V.

Babcock and wilcox boiler

- Working:-The steel drum is filled with water about half of its capacity leaving the rest of it for steam space. the coal is charged onto the grate and burnt. The hot gases move up and down between the baffles in a beneficial path . They transfer heat to the water in the tubes and to the steam in the super-heater in the Zones (1), (2) and (3). Finally, the hot gases exit through the chimney. The draught is regulated by a damper. The portion of water tubes nearer to the furnace are heated to a higher temperature and therefore the density of water decreases and rises into the uptake header and the short tubes along with wet steam. They enter into the steel drum where the steam separates from the water and collects in the steam space. At the same time the water at the back end which is at a lesser temperature enters into water tubes through the long tube and the downtake header. Hence natural circulation of water is established. The steam collected in the steam space is led to the superheater, through the steam pipe which is surrounded by an antipriming pipe. The superheated steam is tapped through the steam stop valve.


BABCOCK & WILCOX BOILERS
Steam and water drum
Safety valve
Stop valve
Pressure gauge
Fusible plug
Anti priming pipe
Manhole
Water level indicator
Feed water inlet
Riser
Superheater
Down comer
Header
Door
Header
Baffles
Furnace
Water tubes
Mud box
Blow-off pipe
Stoker
Grate
Ashpit
Damper
To stack

Modern Boilers

- The modern practice is to generate and use steam at higher pressure and temperature so as to improve the efficiency of the power plant. there are boilers which work in supercritical range i.e. their working pressure is much higher than the critical pressure of steam. The examples of modern high pressure boilers are Benson Boiler, Loeffler Boiler, and La Mont Boiler. The important characteristics of high pressure boilers are as follows:
- **1. Improve Method of Heating:**
- To use solid fuel in the pulverised form.
- To use forced circulation and indirect heating.
- To use preheater to heat the air.
- To increase heat flow through the tubes wall by using hot gases travelling with a supersonic velocity.
- To save latent heat of evaporation by evaporating water at a pressure above critical range.
- To heat water by superheated steam.

- **2. Arrangement of Drums and Tubing:**
- The modern high pressure boilers do not require a large diameter steam separating drum. The drum is either of very small size or is completely absent. In order to avoid large resistance to the flow of water, such boilers are provided with parallel set of tubes.

- **3. Methods of water and Steam Circulation Through the Plant:**
- The modern high pressure boilers use forced circulation system to force water and steam through the boiler circuit which is obtained by using a pump. The manufacturers recommended to use forced circulation when the pressure is above $16 N/mm^2$. The major advantages of forced circulation boilers are as follows:

- Smaller bore and therefore, lighter tubes.

- Absence from scaling troubles due to high circulation velocity.
- Steam can be raised quickly and can meet load changes rapidly.
- More freedom in arrangement of furnace, boiler components and tube layout.
- Uniform heating of all parts eliminates the danger of over-heating and thermal stresses.
- Since the circulation is independent of temperature and pressure, therefore, the boiler can be operated at conditions other than those designed.
- If some external source of power is available, the boiler can be rapidly started from cold.

Chapter 8

Air standard cycles

Air standard cycle

- The cycle based on air standard assumptions is known as air standard cycle.
- Assumptions:-
- 1.The working medium is air.
- 2.The air behaves like an ideal gas.
- 3.All the processes are internally reversible.
- 4.there are no heat losses.
- 5.The composition of fuel remains same as there is no chemical reaction occurs in the working fluid.
- 6.The mass of the working fluid remains constant and there is no inlet or exhaust process.

Condition of reversibility of a cycle

- The thermodynamic process which can be operated in the reverse direction is called reversible process. In thermodynamically reversible process , there should no temperature difference between the hot body and the working substance during any transfer of heat.

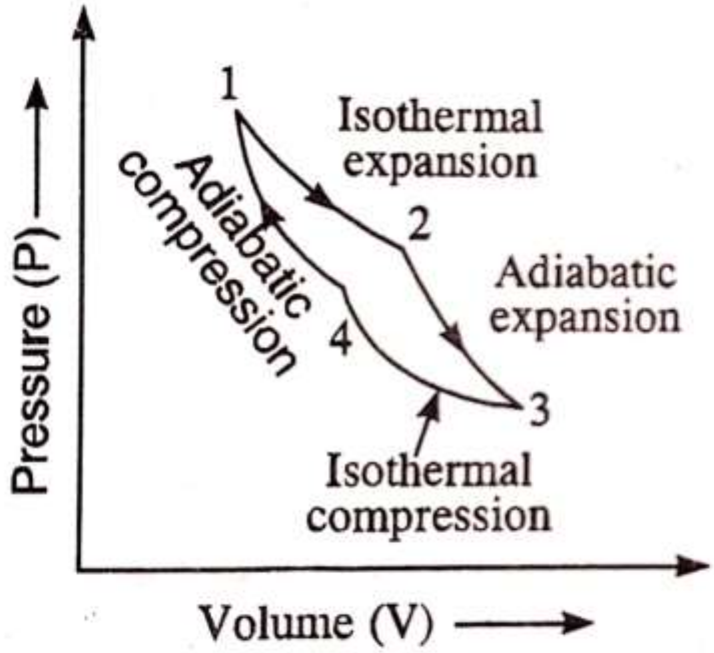
Carnot cycle

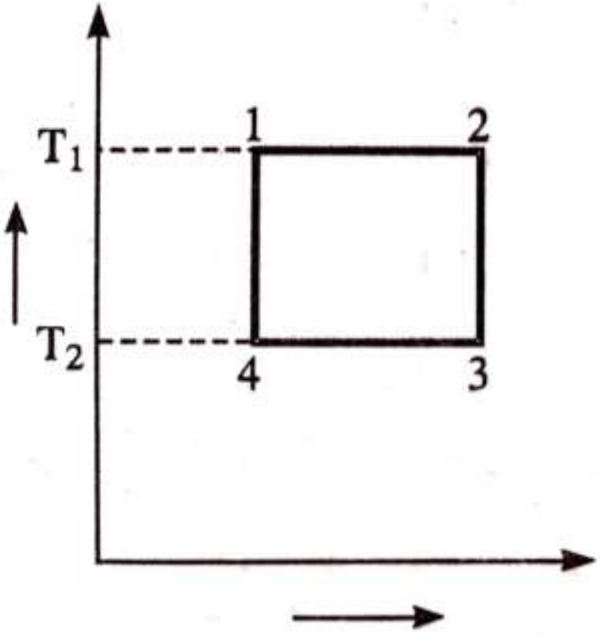
- **Carnot cycle** is an ideal cycle as adopted for an ideal heat engine. It consists of two isothermal process (expansion and compression) and two adiabatic process (expansion and compression).

- The cylinder and piston of the engine are considered as perfect non-conductor of heat but the cylinder cover head is a good conductor of heat. The hot body at a higher temperature is brought in contact with the bottom 'B' of the cylinder. The cylinder is fitted with a weightless and a frictionless piston.

- The french engineer Nicolas Leonard Sadi Carnot was the first scientist who realize the problem of the efficiency of heat engine and invented the **carnot cycle**.

Carnot cycle P-V and T-S diagram





- The sequence of operation of the carnot cycle is as:-
- 1. process 1-2(isothermal expansion):-Heat is supplied at constant temperature T_1 during this process and is equal to work done.
- 2. process 2-3(adiabatic expansion): Air is allowed to expand adiabatically , work is done at cost of internal energy.
- 3. process 3-4(isothermal compression):-Air is compressed isothermally. The heat is rejected by the air to the sink.
- 4 process 4-1(adiabatic compression):-The system returns back to initial state by adiabatic compression.
- Work done= heat supplied –heat rejected
- $= mRT_1 \log r - mRT_2 \log r = mR(T_1 - T_2)\log r$
- Efficiency =work done/heat supplied= $mR(T_1 - T_2)\log r / mRT_1 \log r$
- $= (T_1 - T_2)/ T_1$

Otto cycle

otto cycle is a gas power cycle that is used in spark-ignition internal combustion engines. it is also known as constant volume cycle. It consists of two adiabatic processes and two constant volume processes. The sequence of operation of the otto cycle is as:

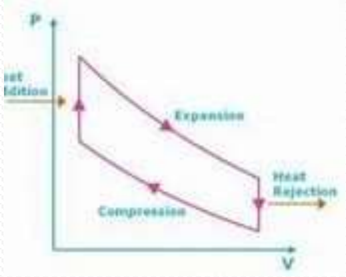
Process 1-2:adiabatic compression

Process 2-3:heat supplied at constant volume

Process 3-4:adiabatic expansion

Process 4-1: heat rejected at constant volume

Otto cycle



Diesel cycle

- The diesel cycle is a compression ignition engine. It is also known as constant pressure cycle. It consists of two adiabatic processes ,one constant pressure and one constant volume process. The sequence of operation of the otto cycle is as:-

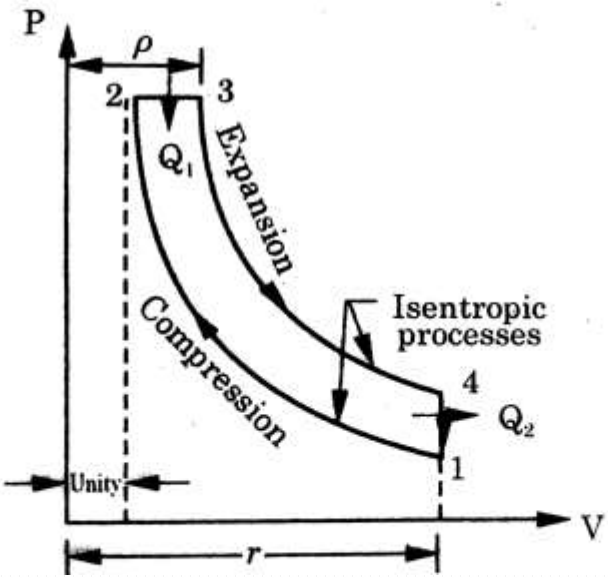
Process 1-2:adiabatic compression

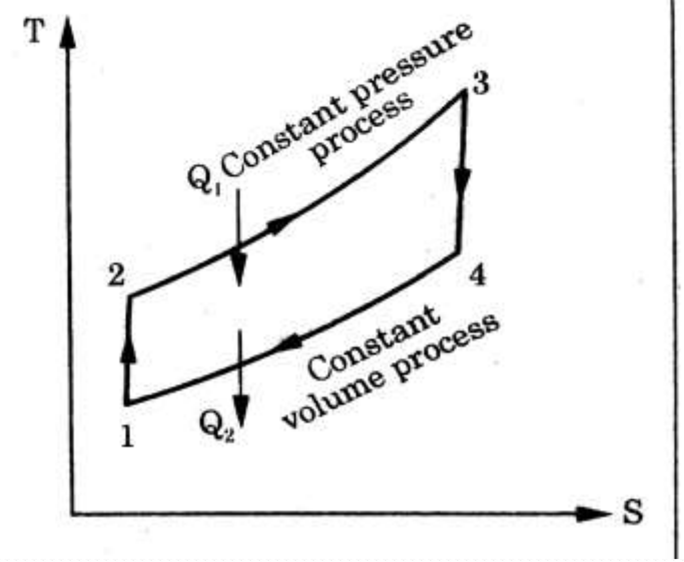
Process 2-3:heat supplied at constant pressure

Process 3-4:adiabatic expansion

Process 4-1: heat rejected at constant volume

Diesel Cycle





Chapter -9

AIR COMPRESSOR

AIR COMPRESSOR

- Air compressor is a device which receives air from atmosphere, compresses the air and increases the pressure with the help of mechanical energy and stores it in storage tank. From storage tank, compressed air can be used for various purposes
- **Uses of compressed air**

- 1. It is used for spray painting.
- 2. It is used in lifts.
- 3. It is used for agriculture work.
- 4. It is used in aircraft industry.
- 5. It is used in chemical industries.
- 6. It is used for air brakes in train, buses etc.

Types of Air compressor

- 1. According to number or stages:-
- (i) Single stage
- (ii) Multi stage
- 2. According to number of cylinders:-
- (i) Single cylinder
- (ii) Multi cylinder
- 3. According to method of cooling:-
- (i) Air cooled
- (ii) Water cooled

- 4. According to capacity:-
- (i) low capacity
- (ii) Medium capacity
- (iii) High capacity
- 5. According to drive:-
- (i) Engine drive
- (ii) Motor drive
- (iii) Belt drive
- 6. According to design:-
- (i) Reciprocating
- (ii) Rotary

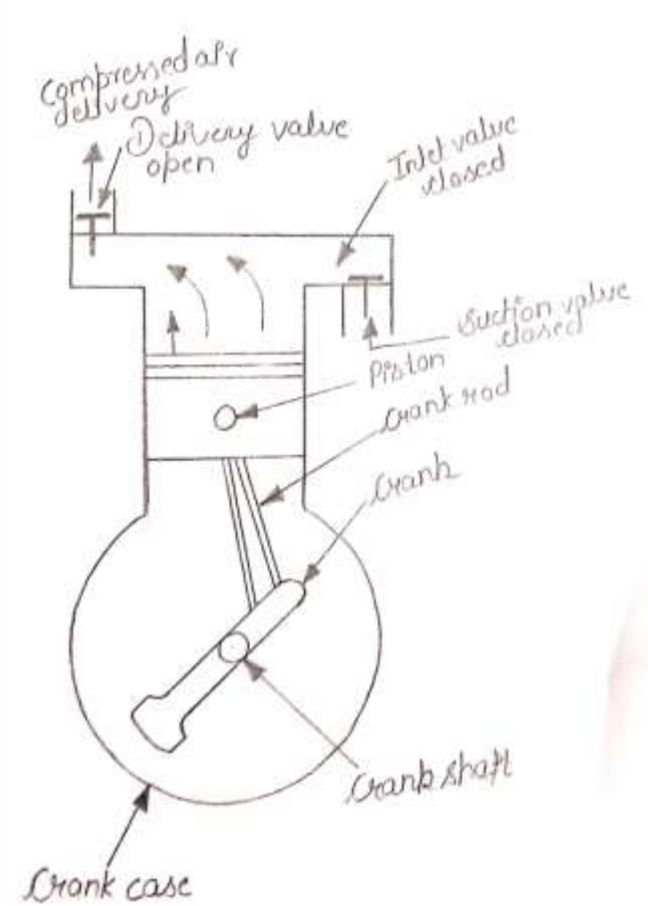
Single stage reciprocating air compressor, its construction and working.

- Single stage reciprocating Air Compressor:-
- It is a type of compressor in which air is drawn into the cylinder during suction stroke through inlet valve and it deliver to the receiver or tank through outlet valve when it is compressed by piston during return stroke.

Construction

- **1. Cylinder**: As the name implies, it is a cylindrical vessel or space in which the piston make a reciprocating motion.
- **2. Piston**: It is a cylindrical component fitted into the cylinder. Its mainly used to transfer force from the expanding air in the cylinder to the crank shaft.
- **3. Inlet Valve**: It is generally used to suck or drawn air from the atmosphere to the cylinder vessel.
- **4. Outlet Valve**: It is used for deliver the compressed air to the receiver.
- **5. Connecting Rod**: It is used to connect the piston and the crankshaft and transmit the motion also.
- **6. Crank Shaft:** It is used for convert the reciprocating forward and backward motion of piston in to Useful rotary motion of shaft.

Single stage reciprocating compressor



Working

- In reciprocating air compressor, when the piston is at the top most position in cylinder and it move downward, with the help of crankshaft, then the pressure inside the cylinder will fall down and the inlet value will be open by pressure difference then the air is drawn in to the cylinder and the piston reached at bottom most position and then inlet valve will be closed during this one stroke of piston is completed.
- After completed one stroke, piston will start move upward and inlet and outlet value will be at closed position. By upward motion of and it reaches to higher value and as soon inside pressure will be more than delivery pressure and then outlet valve will open and compressed air moved to the receiver/tank.
- In which piston make two stroke and crankshaft have one revolution at 360 degree.

Multistage compression

- Multi staging is simply the compression of air or gas into two or more cylinder in place of single cylinder compressor. It is used in reciprocating compressors when pressures of 300 KPa and above are desired in order to:-
- (a)Save power.
- (b)Limit the gas discharge temperature.
- (c)Limit the pressure differential per cylinder.
- (d)Prevent vaporization of lubricating oil and to prevent its ignition if the temperature become too high.

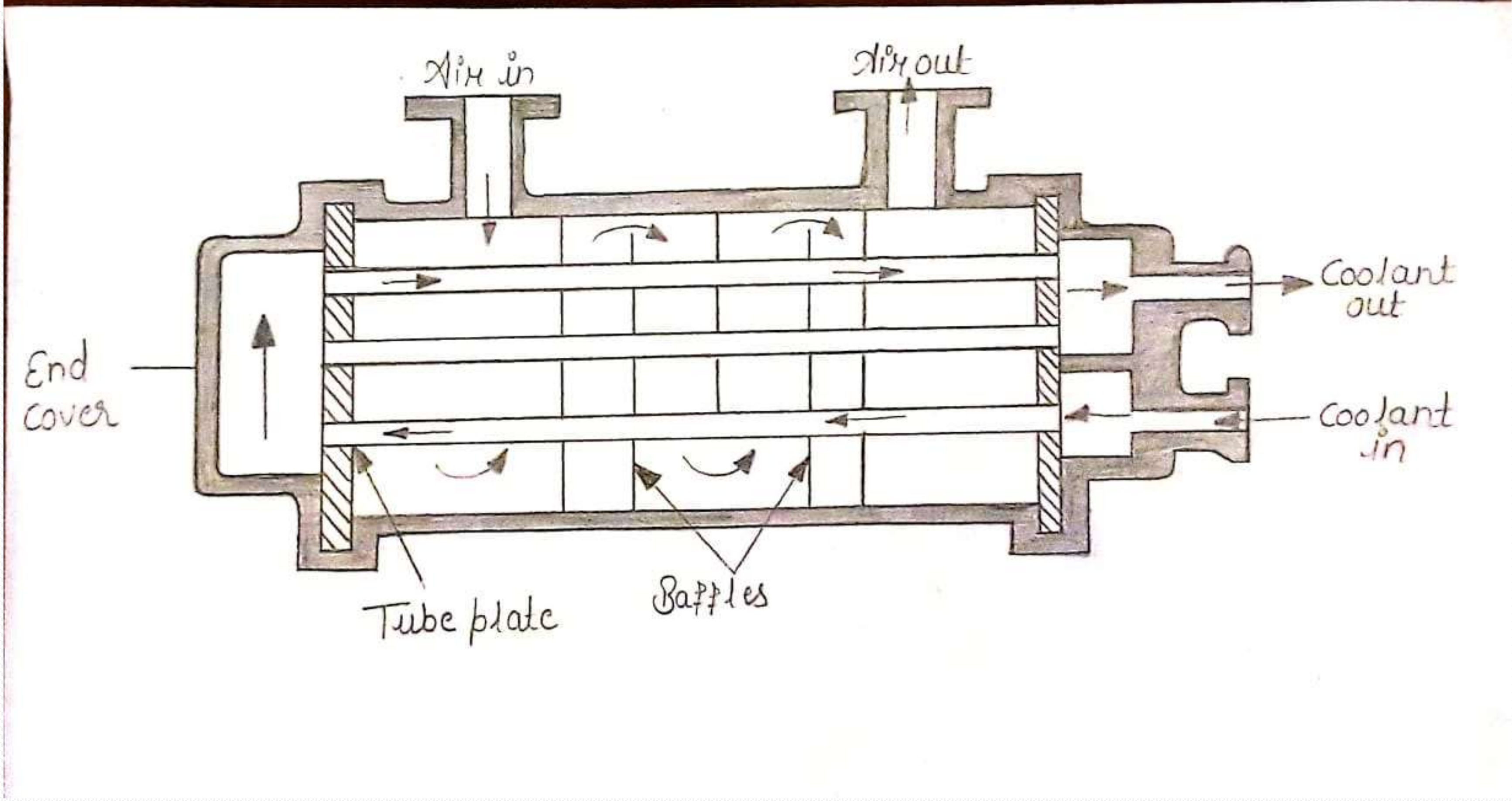
Advantages of multistage compression

- (1)It gives the uniform torque and better mechanical balance and reduce the size of flywheel required.
- (2)The fluid can be compressed to very high pressure.
- (3)The lower temperature range in each stage of compression improve the lubrication.
- (4)Pressure ratio per stage is lowered and it reduce the leakage loss.
- (5)It reduces the cost of compression.
- (6)For a given pressure ratio the multistage arrangement improves volumetric efficiency.

Intercooler

- An intercooler is a mechanical device used to cool gas after compression process .They are used in many applications including air compressor ,air conditioner ,refrigerator and gas turbines and automotive engines.

Intercooler



working

- Turbochargers work by compressing air, increasing its density before it reaches the cylinder of engine. By squeezing more air into each cylinder, the engine is able to burn proportionally more fuel, creating more power with each explosion. This compressing process generates a lot of heat and increases the temperature of the air entering the engine. Unfortunately as air gets hotter, it also becomes less denser reducing the amount of oxygen available in its cylinder and impacting on performance.
- The intercooler works to counteract this process, cooling the compressed air to provide the engine with more Oxygen and improving the combustion in each cylinder. in addition by regulating the temperature of the air, it also increase the reliability of the engine by ensuring the air to fuel ratio in each cylinder is maintained at a safe level.

Types of intercooler

- It is of two types:-
- a) Air to air: It works by passing the compressed air through a network of small tubes. Passed a series of cooling fins the heat transferred from the hot compressed air into this cooling fins which are in turn kept cool by fast flow of air from outside the moving vehicle. Once the cooled compressed air has passed through the intercooler it is then fed to the intake manifold of the engine and into the cylinder
- b) Air to water: This type of intercooler use water to lower the temperature of compressed air-cooled water is pumped through the unit, extracting heat from the air as it passes through the unit. As this water heated up, it then pumped through a radiator or cooling circuit before re-entering the intercooler once cooled .

Condition of minimum work in two stage compressor

- For the condition of minimum work in two stage compressor, there are generally two methods in use for getting isothermal compression. When the compressor is running at high speed.
- 1 **Multi-stage compression:**
- In multi stage compression, compression takes in stages. For minimum compressor efficiency it is desirable to cool air after one stage using inter-cooler.
- In which air is compressed in the low pressure cylinder. After from this air is passed through the intercooler to reduce its temperature and then cooled air is compressed in the high pressure cylinder and in which pressure and temperature reaches at maximum and then it delivers to the receiver/reservoir.
- 2. **Cold water spray:** When the air is compressed in low pressure cylinder it raises its temperature and pressure. For reducing this temperature it will be cool down by spraying cold water rather than use of intercooler. But in actual practice no compression will be isothermal.

Rotory compressor

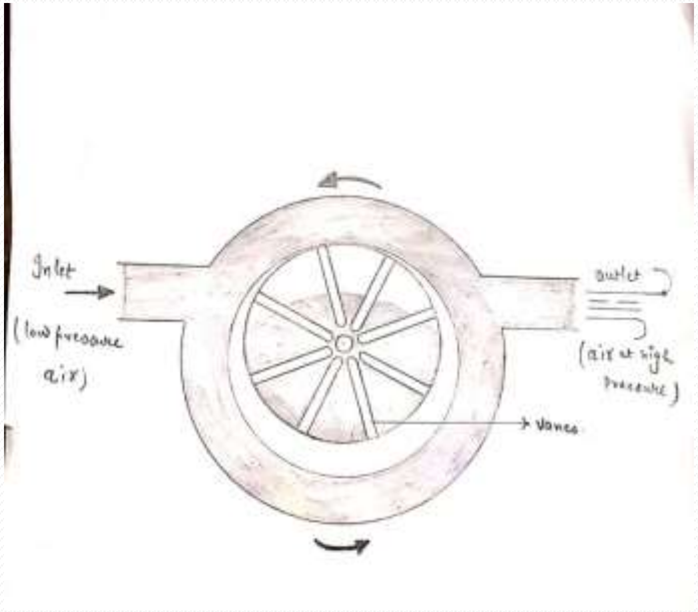
- Rotary compressors are positive displacement machines in which compression and displacement of gas is done by the positive action of rotating elements. In a rotary air compressor, the air is entrapped between two sets of engaging surfaces and the pressure of air is increased by squaring action or back flow of the air.
- **Types of rotary compressor:**

- 1. **Root blower:** It operates by pumping the fluid with a pair of robes.
- 2. **Vane blower:** It operates by back flow of the air.

Vane blower compressor

- A vane blower compressor is a positive displacement compressor which consists of a disc rotating in air tight casing. The disc contains a no.of slots which contains vanes
- **Working**:
- • When the rotor rotates the vanes the centrifugal force develops and the vanes are pressed against the casing and it forms air tight pockets.
- • The rotary motion of vanes compresses the air. When the rotating vanes uncover the outlet, some air under pressure flow back into the casing.
- Therefore, the pressure of air entrapped in the casing is increased by decreasing the volume. The air with pressure is delivered to receiver.

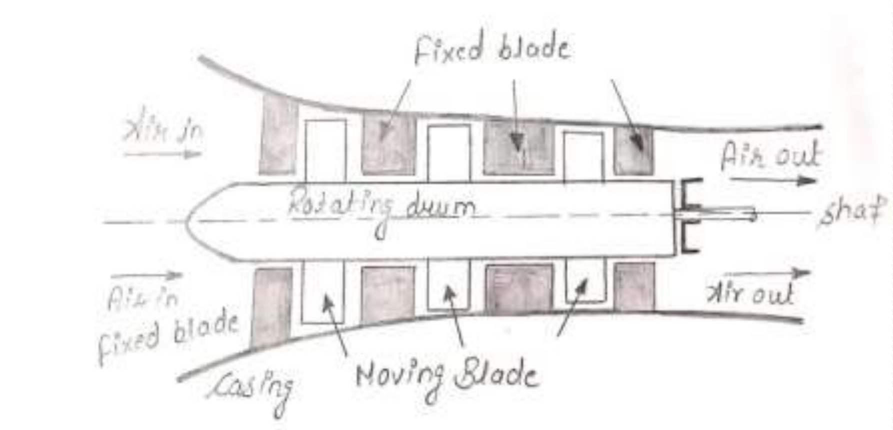
Vane blower compressor



Axial flow compressor

-

- Axial flow compressor is a machine which gives a continuous flow compressed gas.
- It is a rotating, air foil based compressor in which the gas or the working fluid principally flows parallel to the axis of rotation.
- **Working:**
-
- • When the air enters from the atmosphere to the compressor. It flows parallel to the axis of drum and passes through each stage of the compressor.
- • During each stage of the compressor the air gets trapped between the fixed blade and rotating blades and because of this successive compression of air takes place.
- • So, the pressure of air goes on increasing through each stage..Finally, air at high pressure can be delivered to the outlet and can be stored further.


Fixed blade
Air in
Air out
Rotating drum
shaft
Air in
Air out
Fixed blade
Casing
Moving Blade

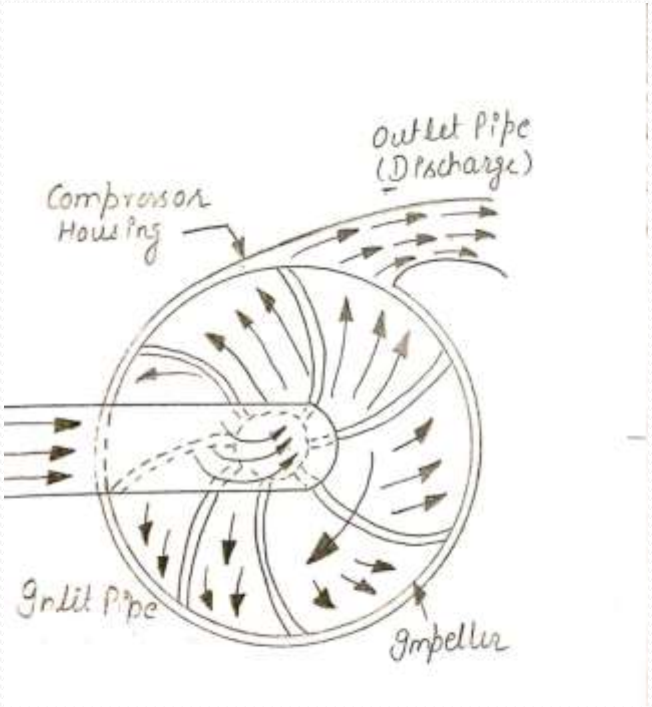
Centrifugal compressor

In this compressor the air reaches the centre of impeller and air is forced outwards by centrifugal force. The diffuser gradually decreases the air velocity. Velocity energy gets converted to high pressure

- Construction:

- A centrifugal compressor generally consists of four components.
- 1) **Casing:** It provides protection and support to other components. It is generally made of cast iron or steel.
- 2) **Impeller**: it is a disc shaped components mounted on a shaft. It receives air from inlet buckets. It consists of radial vanes on it.
- 3) **Diffuser**: it is used to convert the kinetic energy (high velocity) of gas into pressure by gradually slowing the air velocity.
- 4) **Collector**: it is used to collect the air discharged through the diffuser.

Centrifugal compressor



- <u>Working:</u> Air is drawn into the centre of a rotating impeller with low velocity at atmospheric pressure. As the impeller rotates the air moves radially outwards. The rotational energy of the impeller give rise to temperature and pressure of the air. The air goes to the diffuser passage where the velocity decreases (kinetic energy) and converted into pressure energy. This causes further increase in pressure. .Finally, air at high pressure can be delivered to the outlet and can be stored further.