THERMAL ENGINEERING I

SEMESTER:-3RD

BRANCH:-AUTOMOBILE/MECHANICAL ENGINEERING

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TOPICS COVERED:-

- THERMODYNAMIC CONCEPT & TERMINOLOGY
- LAWS OF THERMODYNAMICS
- PROPERTIES PROCESSES OF PERFECT GAS
- INTERNAL COMBUSTION ENGINE
- AIR STANDARD CYCLE
- FUELS AND COMBUSTIOM

UNIT I

THERMODYNAMIC CONCEPT &TERMINOLOGY

System:

A thermodynamic system is defined as a quantity of matter or a region in space which is selected for the study.

Suroundings:

The mass or region outside the system is called surroundings.

Boundary:

The real or imaginary surfaces which separates the system and surroundings is called boundary.
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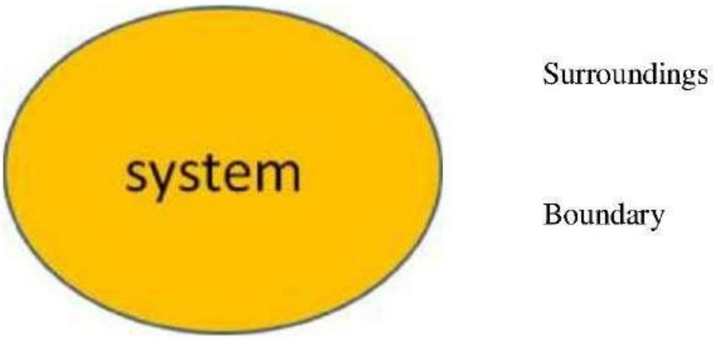


Types of thermodynamic system

On the basis of mass and energy transfer the thermodynamic system is divided into three types.

1. Closed system
2. Open system
3. Isolated system

Closed system: A system in which the transfer of energy but not mass can takes place across the boundary is called closed system. The mass inside the closed system remains constant.

For example: Boiling of water in a closed vessel. Since the water is boiled in closed vessel so the mass of water cannot escapes out of the boundary of the system but heat energy continuously entering and leaving the boundary of the vessel. It is an example of closed system.

Open system: A system in which the transfer of both mass and energy takes place is called an open system. This system is also known as control volume.

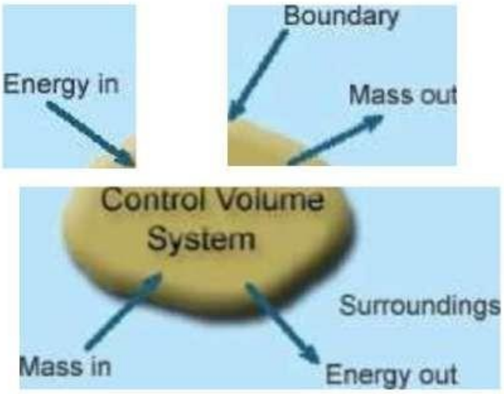
For example: Boiling of water in an open vessel is an example of open system because the water and heat energy both enters and leaves the boundary of the vessel.

Isolated system: A system in which the transfer of mass and energy cannot takes place is called an isolated system.

For example: Tea present in a thermos flask. In this the heat and the mass of the tea cannot cross the boundary of the thermos flask. Hence the thermos flak is an isolated system.

Control Volume:

- ✓ Its a system of fixed volume.
- ✓ This type of system is usually referred to as "open system" or a "control volume" Mass transfer can take place across a control volume.
- ✓ Energy transfer may also occur into or out of the system.
- ✓ Control Surface- Its the boundary of a control volume across which the transfer of both mass and energy takes place.
- ✓ The mass of a control volume (open system) may or may not be fixed.
- ✓ When the net influx of mass across the control surface equals zero then the mass of the system is fixed and vice-versa.
- ✓ The identity of mass in a control volume always changes unlike the case for a control mass system (closed system).
- ✓ Most of the engineering devices, in general, represent an open system or control volume.



Example:
Heat exchanger - Fluid enters and leaves the system continuously with the transfer of heat across the system boundary.
Pump - A continuous flow of fluid takes place through the system with a transfer of mechanical energy from the surroundings to the system

Thermodynamic Equilibrium:

A thermodynamic system is said to exist in a state of thermodynamic equilibrium when no change in any macroscopic property is registered if the system is isolated from its surroundings.

An isolated system always reaches in the course of time a state of thermodynamic equilibrium and can never depart from it spontaneously.

Therefore, there can be no spontaneous change in any macroscopic property if the system exists in an equilibrium state. A thermodynamic system will be in a state of thermodynamic equilibrium if the system is the state of Mechanical equilibrium, Chemical equilibrium and Thermal equilibrium.

- & Mechanical equilibrium: The criteria for Mechanical equilibrium are the equality of pressures.
- & Chemical equilibrium: The criteria for Chemical equilibrium are the equality of chemical potentials.
- & Thermal equilibrium: The criterion for Thermal equilibrium is the equality of temperatures.

State:

The thermodynamic state of a system is defined by specifying values of a set of measurable properties sufficient to determine all other properties. For fluid systems, typical properties are pressure, volume and temperature. More complex systems may require the specification of more unusual properties. As an example, the state of an electric battery requires the specification of the amount of electric charge it contains.

Property:

Properties may be extensive or intensive.

Intensive properties: The properties which are independent of the mass of thesystem. For example: Temperature, pressure and density are the intensive properties.

Extensive properties: The properties which depend on the size or extent of the system are called extensive properties.

For example: Total mass, total volume and total momentum.

Process:

When the system undergoes change from one thermodynamic state to final state due change in properties like temperature, pressure, volume etc, the system is said to have undergone thermodynamic process.

Various types of thermodynamic processes are: isothermal process, adiabatic process, isochoric process, isobaric process and reversible process.

Cycle:

Thermodynamic cycle refers to any closed system that undergoes various changes due to temperature, pressure, and volume, however, its final and initial state are equal. This cycle is important as it allows for the continuous process of a moving piston seen in heat engines and the expansion/compression of the working fluid in refrigerators, for example. Without the cyclical process, a car wouldn't be able to continuously move when fuel is added, or a refrigerator would not be able to stay cold.

Visually, any thermodynamic cycle will appear as a closed loop on a pressure volume diagram.

Examples: Otto cycle, Diesel Cycle, Brayton Cycle etc.

Reversibility:

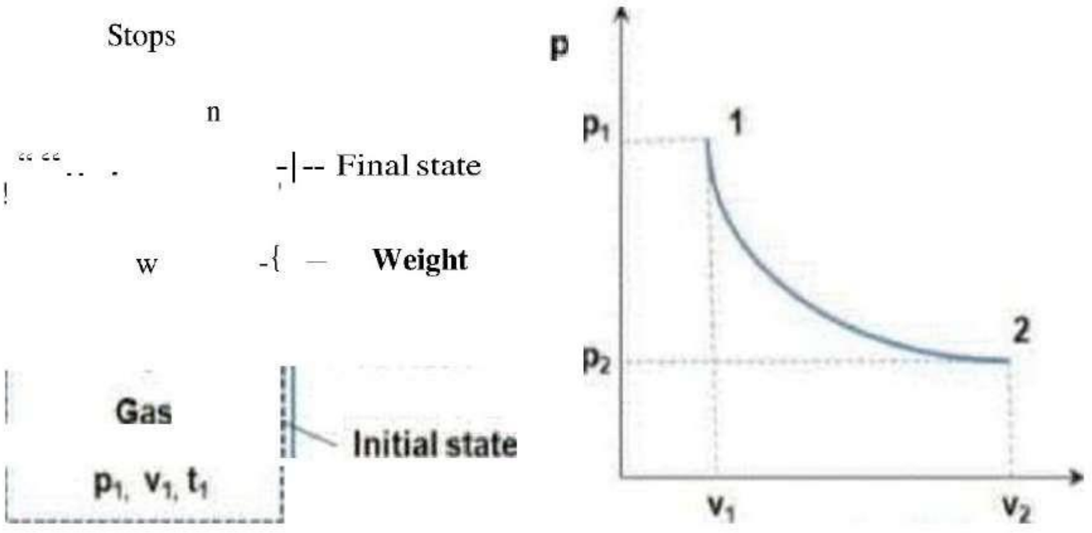
Reversibility, in thermodynamics, a characteristic of certain processes (changes of a system from an initial state to a final state spontaneously or as a result of interactions with other systems) that can be reversed, and the system restored to its initial state, without leaving net effects in any of the systems involved.

An example of a reversible process would be a single swing of a frictionless pendulum from one of its extreme positions to the other. The swing of a real pendulum is irreversible because a small amount of the mechanical energy of the pendulum would be expended in performing work against frictional forces, and restoration of the pendulum to its exact starting position would require the supply of an equivalent amount of energy from a second system, such as a compressed spring in which an irreversible change of state would occur.

Quasi static process:

When a process is processing in such a way that system will be remained infinitesimally close with equilibrium state at each time, such process will be termed as quasi static process or quasi equilibrium process.

In simple words, we can say that if system is going under a thermodynamic process through succession of thermodynamic states and each state is equilibrium state then the process will be termed as quasi static process.



We will see one example for understanding the quasi static process, but let us consider one simple example for better understanding of quasi static process. If a person is coming down from roof to ground floor with the help of ladder steps then it could be considered as quasi static process. But if he jumps from roof to ground floor then it will not be a quasi static process.
Weight placed over the piston is just balancing the force which is exerted in upward direction by gas. If we remove the weight from the piston, system will have unbalanced force and piston will move in upward direction due to force acting over the piston in upward direction by the gas.

Irreversible Process:

The irreversible process is also called the natural process because all the processes occurring in nature are irreversible processes. The natural process occurs due to the finite gradient between the two states of the system. For instance, heat flow between two bodies occurs due to the temperature gradient between the two bodies; this is in fact the natural flow of heat. Similarly, water flows from high level to low level, current moves from high potential to low potential, etc.

& In the irreversible process the initial state of the system and surroundings cannot be restored from the final state.
- During the irreversible process the various states of the system on the path of change from initial state to final state are not in equilibrium with each other.
- During the irreversible process the entropy of the system increases decisively and it cannot be reduced back to its initial value.
- The phenomenon of a system undergoing irreversible process is called as irreversibility.

Causes of Irreversibility:

Friction: Friction is invariably present in real systems. It causes irreversibility in the process as work done does not show an equivalent rise in the kinetic or potential energy of the system. The fraction of energy wasted due to frictional effects leads to deviation from reversible states.

Free expansion: Free expansion refers to the expansion of unresisted type such as expansion in a vacuum. During this unresisted expansion the work interaction is zero, and without the expense of any work, it is not possible to restore initial states. Thus, free expansion is irreversible.

Heat transfer through a finite temperature difference: Heat transfer occurs only when there exist temperature difference between bodies undergoing heat transfer. During heat transfer, if heat addition is carried out in a finite number of steps then after every step the new state shall be a non-equilibrium state.

Nonequilibrium during the process: Irreversibilities are introduced due to lack of thermodynamic equilibrium during the process. Non-equilibrium may be due to mechanical inequilibrium, chemical inequilibrium, thermal inequilibrium, electrical inequilibrium, etc. and irreversibility is called mechanical irreversibility, chemical irreversibility, thermal irreversibility, electrical irreversibility respectively. Factors discussed above are also causing non-equilibrium during the process and therefore make process irreversible.

Heat:

It is the energy in transition between the system and the surroundings by virtue of the difference in temperature Heat is energy transferred from one system to another solely by reason of a temperature difference between the systems. Heat exists only as it crosses the boundary of a system and the direction of heat transfer is from higher temperature to lower temperature. For thermodynamics sign convention, heat transferred to a system is positive; Heat transferred from a system is negative.

Work:

Thermodynamic definition of work: Positive work is done by a system when the sole effect external to the system could be reduced to the rise of a weight.

Work done BY the system is positive and work done ON the system is negative.

Types of work interaction:

& Expansion and compression work (displacement work) &
Work of a reversible chemical cell
& Work in stretching of a liquid surface &
Work done on elastic solids
& Work of polarization and magnetization

Point and Path functions:

& Point function does not depend on the history (or path) of the system. It only depends on the state of the system.

& Examples of point functions are: temperature, pressure, density, mass, volume, enthalpy, entropy, internal energy etc.

& Path function depends on history of the system (or path by which system arrived at a given state).

& Examples for path functions are work and heat.

& Path functions are not properties of the system, while point functions are properties of the system.

& Change in point function can be obtained by from the initial and final values of the function, whereas path has to defined in order to evaluate path functions.

ENERGY:- Energy is the capacity for doing work. It may exist in potential, kinetic, thermal, helectrical, chemical, nuclear, or other forms.

Energy are of two types

1.stored energy

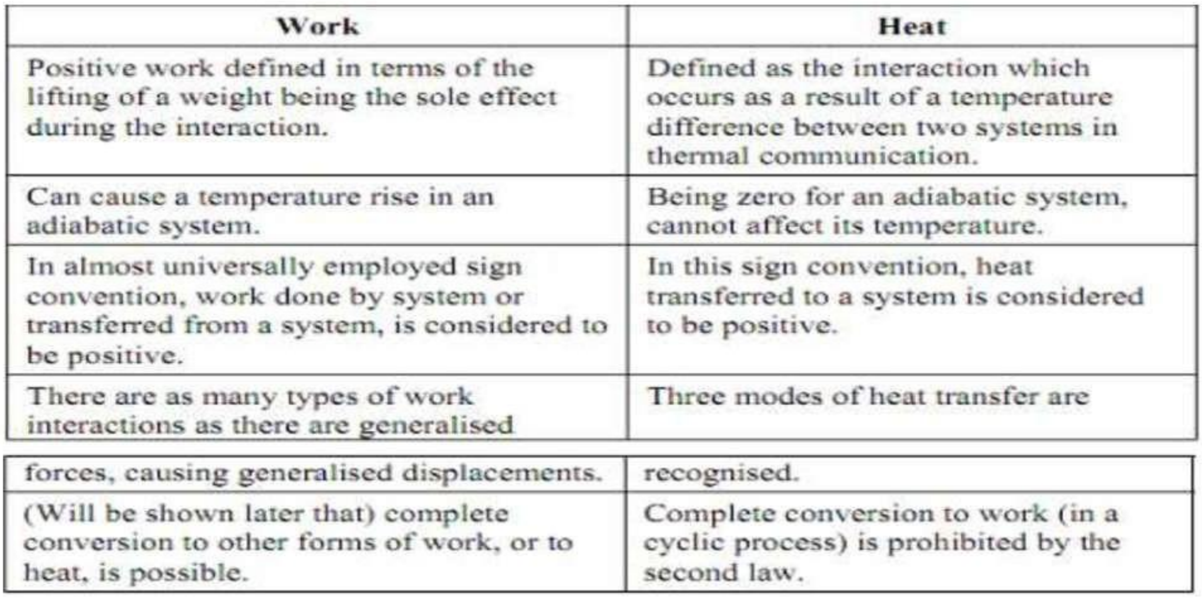
a)Potential energy(Mgh)

b)Kinetic energy(1/2Mv$^{2)}$

c)Internal energy(U)

2.Transitional energy

DIFFERENCE BETWEEN WORK AND HEAT



Work	Heat
Positive work defined in terms of the lifting of a weight being the sole effect during the interaction.	Defined as the interaction which occurs as a result of a temperature difference between two systems in thermal communication.
Can cause a temperature rise in an adiabatic system.	Being zero for an adiabatic system, cannot affect its temperature.
In almost universally employed sign convention, work done by system or transferred from a system, is considered to be positive.	In this sign convention, heat transferred to a system is considered to be positive.
There are as many types of work interactions as there are generalised forces, causing generalised displacements.	Three modes of heat transfer are recognised.
(Will be shown later that) complete conversion to other forms of work, or to heat, is possible.	Complete conversion to work (in a cyclic process) is prohibited by the second law.

Displacement Work

Consider a piston cylinder arrangement as given in the Figure 2.4. If the pressure of the fluid is greater than that of the surroundings, there will be an unbalanced force on the face of the piston. Hence, the piston will move towards right.

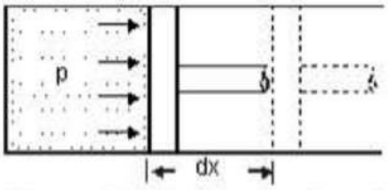


Figure 2.4 Displacement work

Force acting on the piston =Pressure×Area

=pA

∴ Work done =Force ×distance

=pA ×dx

=pdV

where dV - change in volume.

This work is known as displacement work or pdV work corresponding to the elemental displacement dx. To obtain the total work done in a process, this elemental work must be added from the initial state to the final state.

The displacement work for different processes :

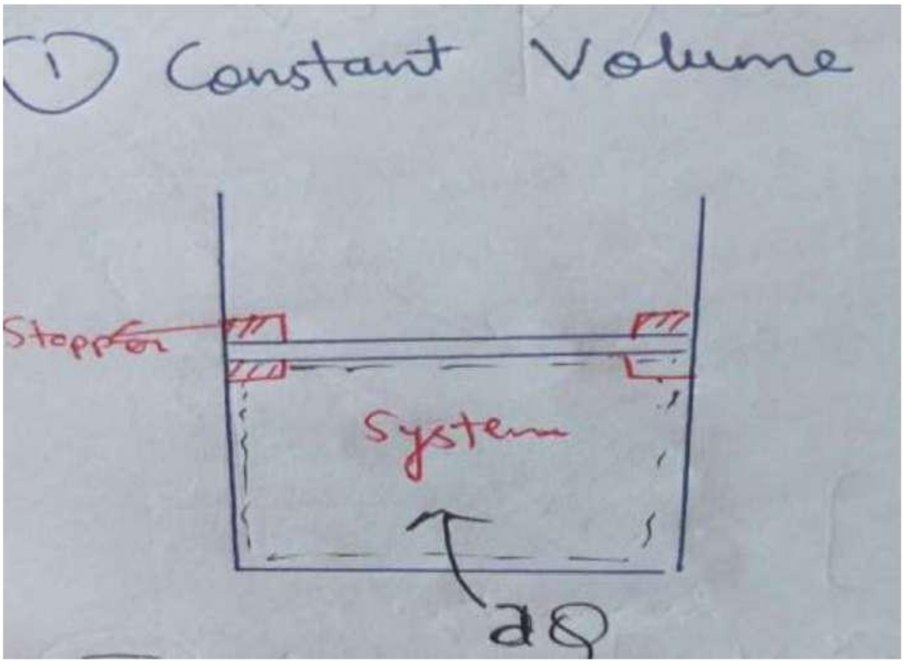
(a) Isochoric Process :

The process for which the volume remains constant is Isochoric Process.

Volume = constant

Therefore , $\Delta W = 0$. (Because $dV = 0$)

This process is a constant volume process , identified by rigid container.



(b) Isobaric Process :

The process for which the prsssure remains constant is Isobaric Process

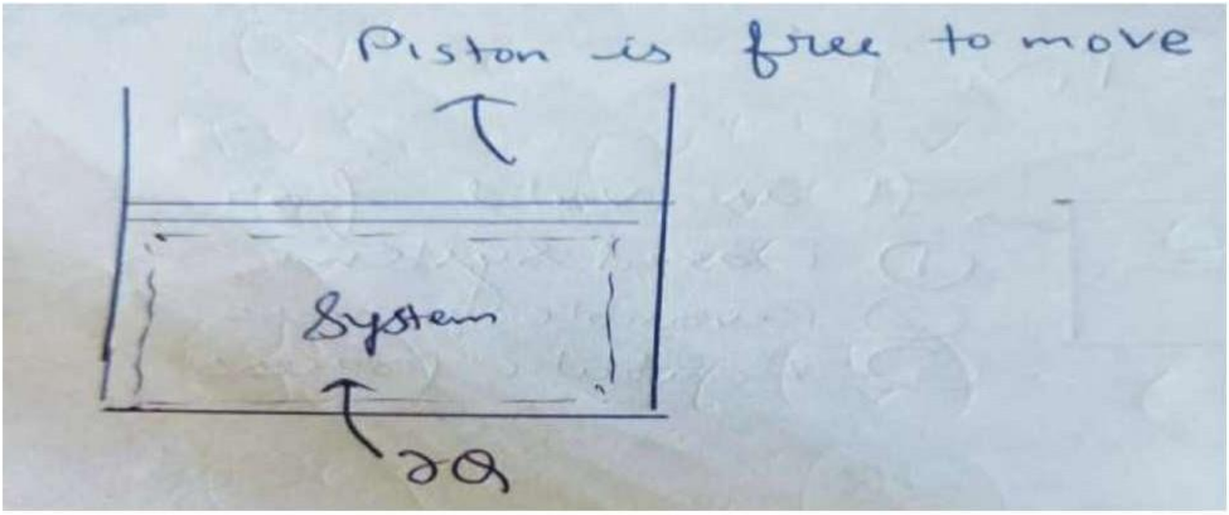
Pressure = P = constant

$$\partial \omega = \int p\,dV$$

$$\partial \omega = P \int_{V_1}^{V_2} dV = P(V_2 - V_1)$$

$$\partial \omega = P\,(V_2 - V_1)$$

Therefore , $\Delta W = P\ (V_2 - V_1)$



This process is a constant pressure process identified by pistons restricted movement .

(c) Isothermal process :

The thermodynamic process for which the temperature remains constant is isothermal process.

Temperature = T = constant

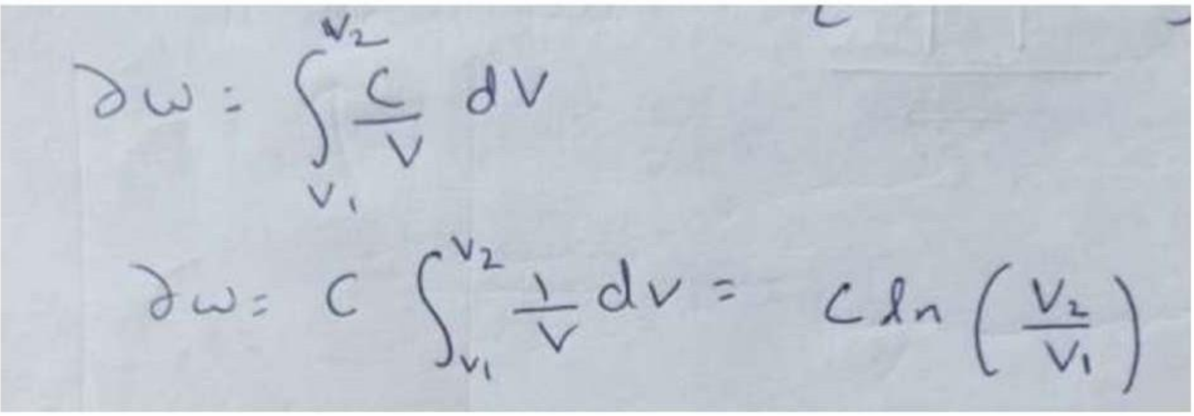
We know that ,

PV = mRT

P = mRT/V ; Assume , c = mRT

PV = c ; P'V' = PV = c

$\{V_2/V_1 = P_1/P_2\}$



$$\partial w = \int_{V_1}^{V_2} \frac{c}{V}\, dV$$

$$\partial w = c \int_{V_1}^{V_2} \frac{1}{V}\, dv = c \ln\left(\frac{V_2}{V_1}\right)$$

$\Delta W = P_1 V_1 \ln (V_2/V_1) = mRT_1 \ln (P_1/P_2)$

Note : The above result is valid only for :

- **Close system**
- **Reversible process**
- **Ideal gas**

The Isothermal process is identified by phase change .

(d) Adiabatic Process :

The thermodynamic process for which the net heat transfer is zero , such process is Adiabatic Process.

This thermodynamic process is identified by insulated container.

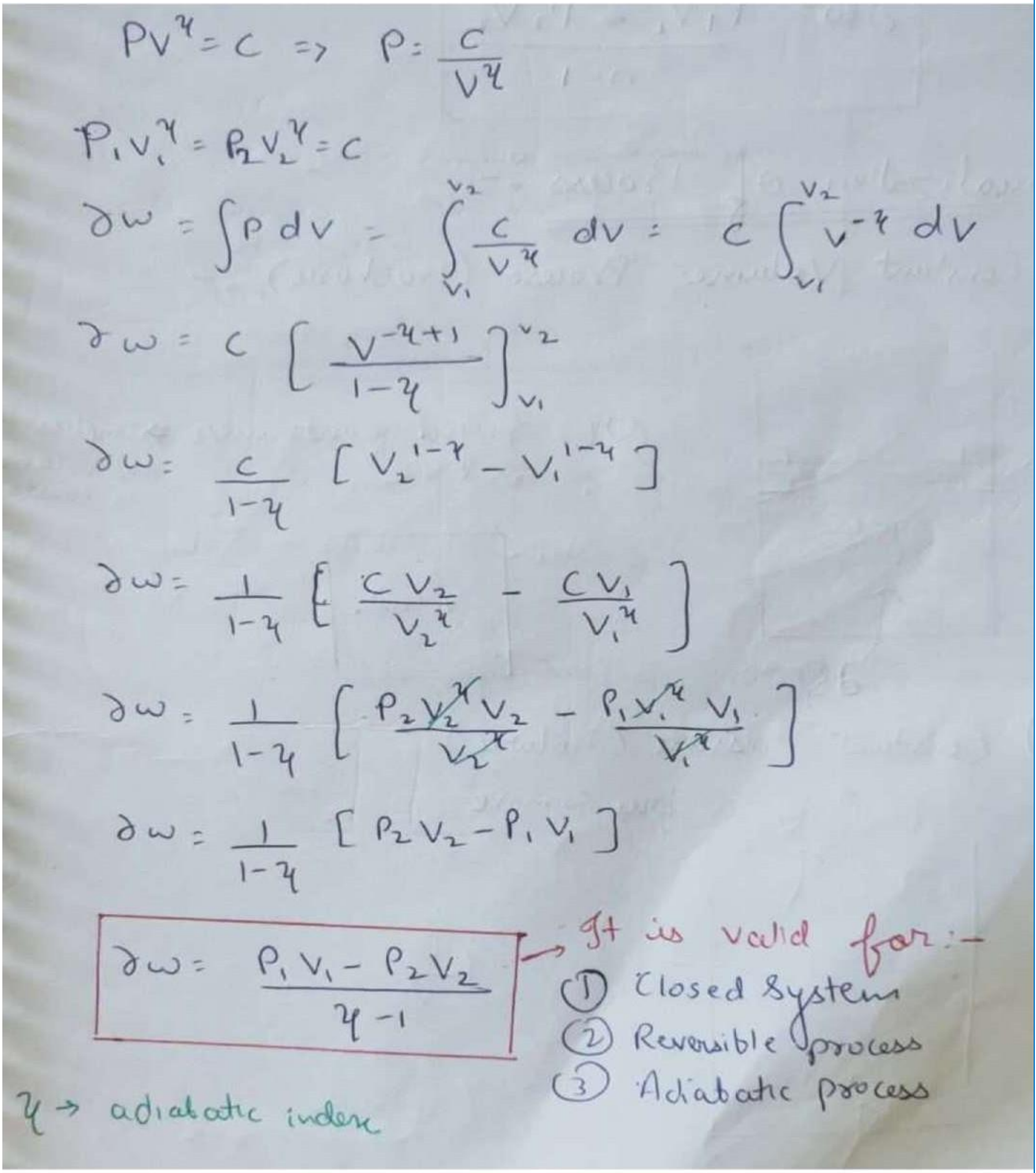
for Adiabatic Process , PV^{x} = constant

Here ,

¥= Gamma = Adiabatic index

and it is valid only for :

1. **Reversible process**
2. **Adiabatic Process**



$$PV^{\gamma} = C \Rightarrow P = \frac{C}{V^{\gamma}}$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = C$$

$$\partial w = \int P\,dV = \int_{V_1}^{V_2} \frac{C}{V^{\gamma}}\,dV = C\int_{V_1}^{V_2} V^{-\gamma}\,dV$$

$$\partial w = C\left[\frac{V^{-\gamma+1}}{1-\gamma}\right]_{V_1}^{V_2}$$

$$\partial w = \frac{C}{1-\gamma}\left[V_2^{1-\gamma} - V_1^{1-\gamma}\right]$$

$$\partial w = \frac{1}{1-\gamma}\left[\frac{C V_2}{V_2^{\gamma}} - \frac{C V_1}{V_1^{\gamma}}\right]$$

$$\partial w = \frac{1}{1-\gamma}\left[\frac{P_2 \cancel{V_2^{\gamma}} V_2}{\cancel{V_2^{\gamma}}} - \frac{P_1 \cancel{V_1^{\gamma}} V_1}{\cancel{V_1^{\gamma}}}\right]$$

$$\partial w = \frac{1}{1-\gamma}\left[P_2 V_2 - P_1 V_1\right]$$

$$\boxed{\partial w = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}} \rightarrow$$

It is valid for:-

① Closed System

② Reversible process

③ Adiabatic process

$\gamma \rightarrow$ adiabatic index

$\Delta W = (P_1 V_1 - P_2 V_2) / (\text{¥} - 1)$

Note : The above result is valid only for :

1. Closed system
2. Reversible process
3. Adiabatic process

(e) Polytropic process :

This is the thermodynamics process which obeys the following relation :

$$PV^N = C$$

Here , P = pressure

V = volume

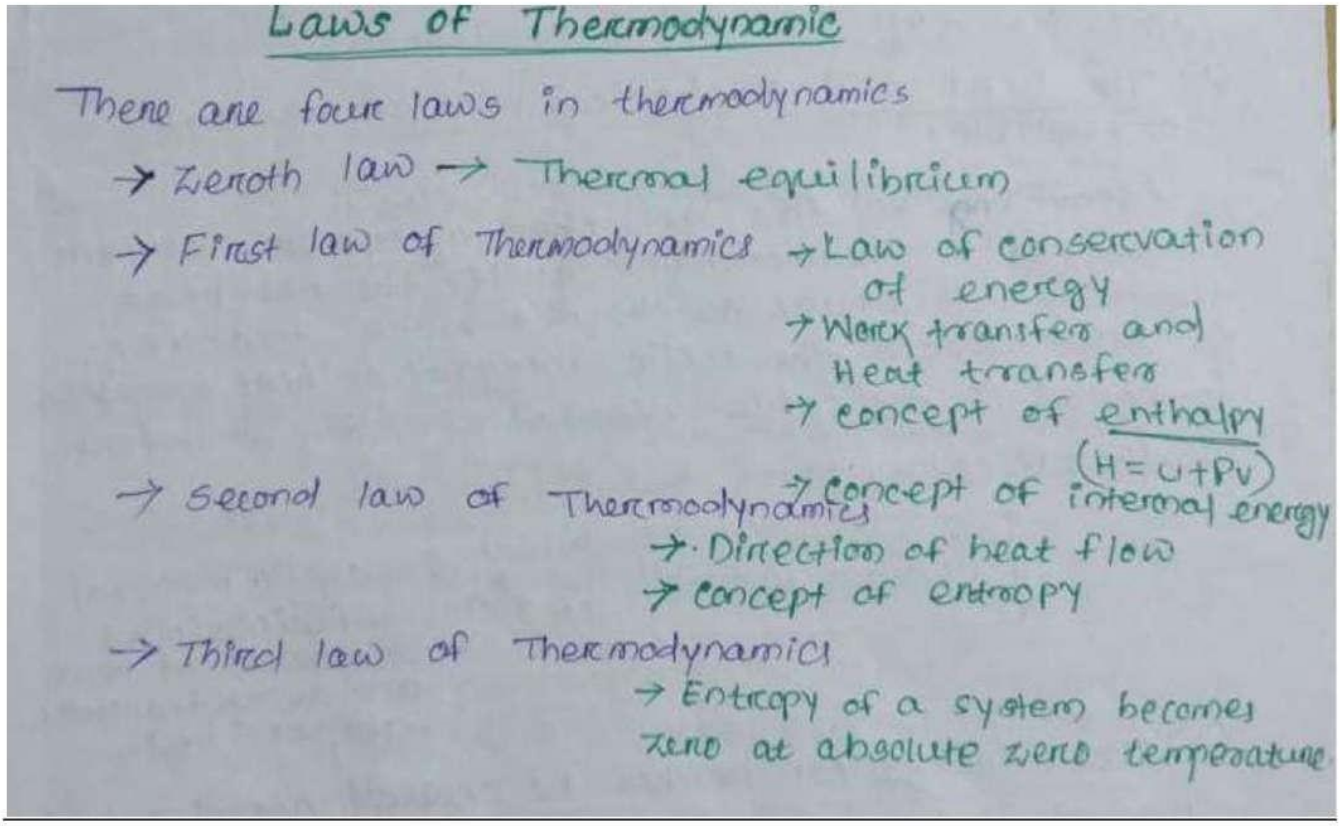
N = polytropic index

C = constant

Generally , 1 < N < ¥

$\Delta W = (P_1V_1 - P_2V_2) / (N - 1)$

UNIT II
LAWS OF THERMODYNAMICS



Laws of Thermodynamic

There are four laws in thermodynamics

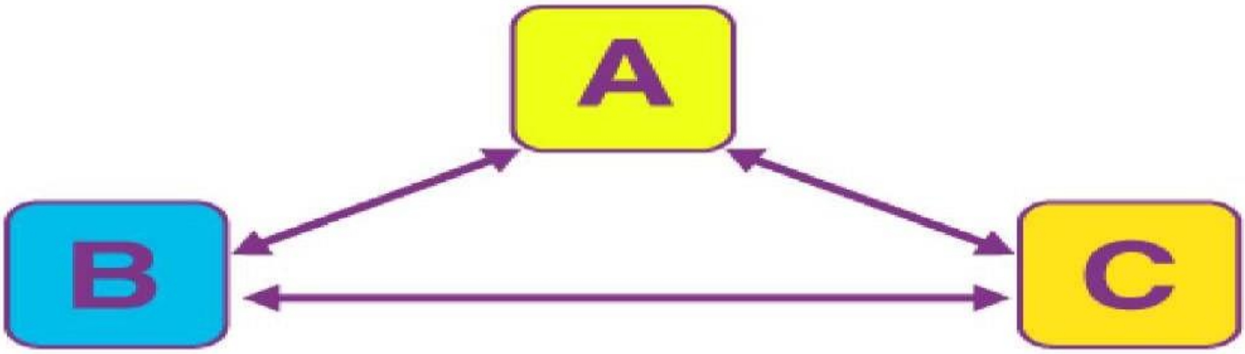
→ Zeroth law → Thermal equilibrium

→ First law of Thermodynamics
  → Law of conservation of energy
  → Work transfer and Heat transfer
  → concept of enthalpy $(H = U + PV)$
  → concept of internal energy

→ Second law of Thermodynamics
  → Direction of heat flow
  → concept of entropy

→ Third law of Thermodynamics
  → Entropy of a system becomes zero at absolute zero temperature

ZEROTH LAW OF THERMODYNAMICS:-The zeroth law of thermodynamics states that if two thermodynamic systems are each in thermal equilibrium with a third system, then they are in thermal equilibrium with each other.

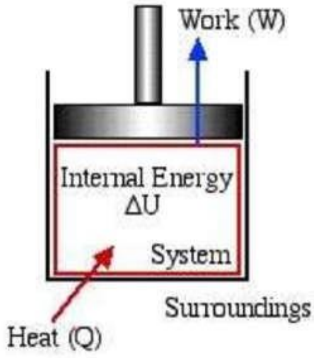


According to this law, if systems B and C separately are in thermal equilibrium with another system A, then systems B and C will also be in thermal equilibrium with each other. This is also the principle by which thermometers are used.

FIRST LAW OF THERMODYNAMIC:-The first law of thermodynamics is a version of the law of conservation of energy, adapted for thermodynamic processes, distinguishing three kinds of transfer of energy, as heat, as thermodynamic work, and as energy associated with matter transfer, and relating them to a function of a body's state, called internal energy.

The law of conservation of energy states that the total energy of any isolated system (for which energy and matter transfer through the system boundary are not possible) is constant; energy can be transformed from one form to another, but can be neither created nor destroyed.

We consider the First Law of Thermodynamics applied to stationary closed systems as a conservation of energy principle. Thus energy is transferred between the system and the surroundings in the form of heat and work, resulting in a change of internal energy of the system. Internal energy change can be considered as a measure of molecular activity associated with change of phase or temperature of the system and the energy equation is represented as follows:



Energy Equation for Stationary Closed Systems:

$$\boxed{Q - W = \Delta U}\ [\mathrm{kJ}]$$

where: Q is the Heat Transferred to the System

W is the Work Done by the System

ΔU is the Change of Internal Energy

Dividing each term by the system mass m $[\mathrm{kg}]$ we obtain the specific form of the Energy Equation:

$$\boxed{q - w = \Delta u}\ \left[\mathrm{kJ}/\mathrm{kg}\right]$$

Energy Equation for Stationary Closed Systems

Limitations of the First Law:

- *The* first law of thermodynamics merely indicates that in any process there is a transformation between the various forms of energy involved in the process but provides no information regarding the feasibility of such transformation.
- First law does not provide any information regarding the direction processes will take whether it is a spontaneous or a non spontaneous process.

APPLICATION OF FIRST LAW OF THERMODYNAMICS:-

FLOW PROCESS:- An open system which permits the transfer of mass from the system is called flow process.

There are two types of flow process

- Steady flow process
- Unsteady flow process

CONDITION FOR A STEADY FLOW PROCESS:-When a flow process is satisfying the following conditions, it is known as a steady flow process.

1. The mass and energy content of the control volume remains constant with time.

2. The state and energy of the fluid at inlet, at the exit and at every point within the control volume are time independent.

3. The rate of energy transfer in the form of work and heat across the control surface is constant with time.

Therefore for a steady flow process

$M_{IN} = M_{OUT}$

STEADY FLOW ENERGY EQUATION:- Since the steady flow process is that in which the condition of fluid flow within a control volume do not vary with time, i.e. the mass flow rate, pressure, volume, work and rate of heat transfer are not the function of time.

i.e., for steady flow

(dm/dt)entrance = (dm/dt)exit ;

i.e, dm/dt = constant

dP/dt = dV/dt = dρ/dt = dEchemical = 0

Assumptions:-

The following conditions must hold good in a steady flow process.

(a) The mass flow rate through the system remains constant.

(b) The rate of heat transfer is constant.

(c) The rate of work transfer is constant.

(d) The state of working:; substance at any point within the system is same at all times.

(e) There is no change in the chemical composition of the system. If any one condition is not satisfied, the process is called unsteady process.

Let; A1, A2 = Cross sectional Area at inlet and outlet

ρ1,ρ2 = Density of fluid at inlet and outlet

m1,m2 = Mass flow rate at inlet and outlet

u1,u2 = I.E. of fluid at inlet and outlet

P1,P2 = Pressure of mass at inlet and outlet

v1, v2 = Specific volume of fluid at inlet and outlet

V1,V2 = Velocity of fluid at inlet and outlet

Z1, Z2 = Height at which the mass enter and leave

Q = Heat transfer rate

W = Work transfer rate Consider open system; we have to consider mass balanced as well as energy balance.

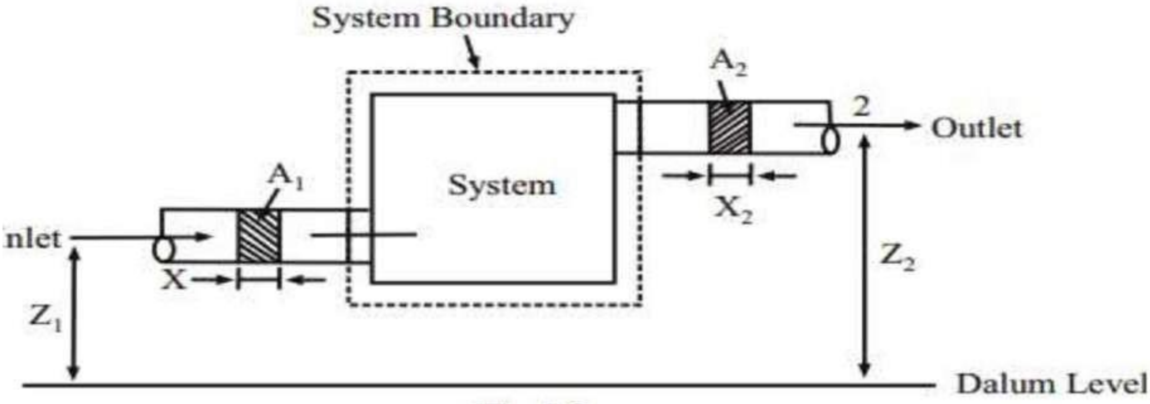


Fig 2.3

In the absence of any mass getting stored the system we can write;

Mass flow rate at inlet = Mass flow rate at outlet i.e., mf1 = mf2

since mf = density X volume flow rate = density X Area X velocity

= ρ.A.V ρ1.A1.V1 = ρ2.A2.V2

or, A1.V1/v1 = A2.V2/v2; v1, v2

= specific volume Now total energy of a flow system consist of P.E, K.E., I.E., and flow work

Hence, E = PE + KE + IE + FW = h + V2/2 + gz Now;

Total Energy rate cross boundary as heat and work

= Total energy rate leaving at (2) - Total energy rate leaving at (1)

Application of SFEE

SFEE governs the working of a large number of components used in many engineering practices. In this section a brief analysis of such components working under steady flow conditions are given and the respective governing equations are obtained.

Turbines

Turbines are devices used in hydraulic, steam and gas turbine power plants. As the fluid passes□through□ the turbine, work is done on the blades of the turbine which are attached to a shaft. Due to the work given to the blades, the turbine shaft rotates producing work.

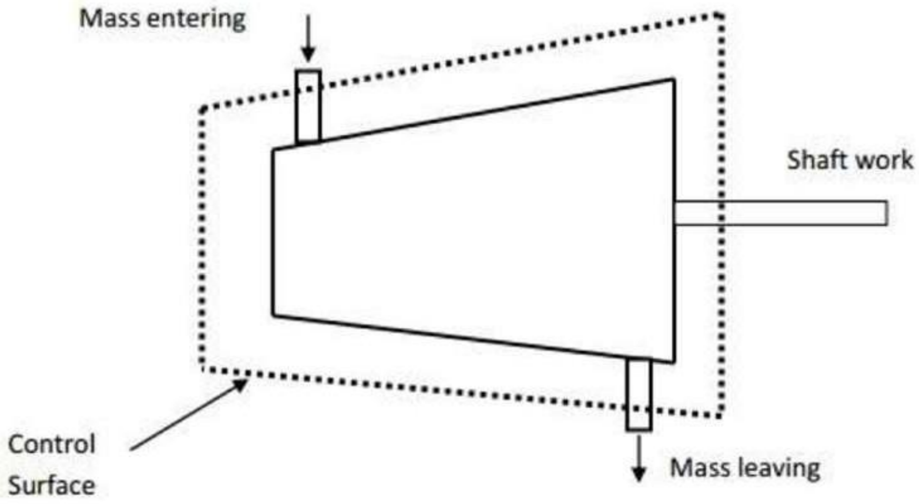


Figure 3.4 Schematic Representation of a Turbine

General Assumptions

1. Changes in kinetic energy of the fluid are negligible
2. Changes in potential energy of the fluid are negligible.

$$[Q-W]=m[(h_2 - h_1)]$$

Compressors

Compressors (fans and blowers) are work consuming devices, where a low-pressure fluid is compressed by utilising mechanical work. Blades attached to the shaft of the turbine imparts kinetic energy to the fluid which is later converted into pressure energy.

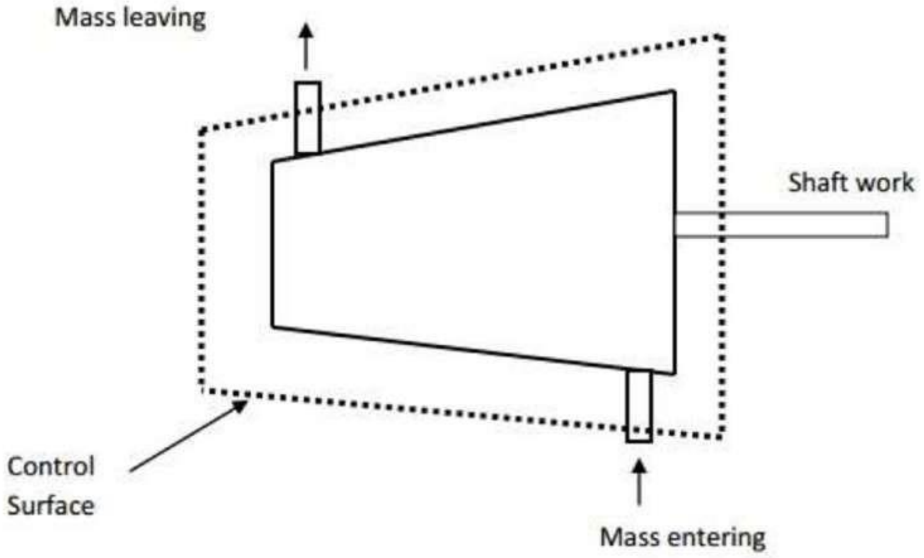


Figure 3.5 Schematic Representation of a Compresso

General Assumptions

1. Changes in the kinetic energy of the fluid are negligible
2. Changes in the potential energy of the fluid are negligible

Governing Equation

Applying the above equations SFEE becomes

$$[Q-W]=m[(h_2 - h_1)]$$

Pumps

Similar to compressors pumps are also work consuming devices. But pumps handle incompressible fluids, whereas compressors deal with compressible fluids.

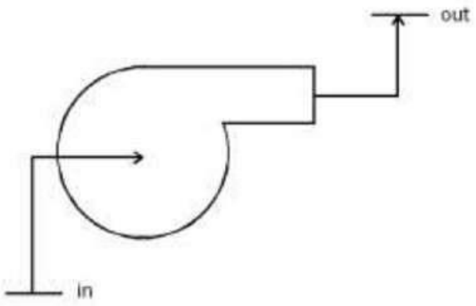


Figure 3.6 Schematic diagram of a pump

General Assumptions

1. No heat energy is gained or lost by the fluids;

2. Changes in kinetic energy of the fluid are negligible.

Governing Equation

$$\left[-\dot{W}\right] = \dot{m}\left[(h_2 - h_1) + (Z_2 - Z_1)g\right] \quad ...(3.13)$$

As the fluid passes through a pump, enthalpy of the fluid increases, (internal energy of the fluid remains constant) due to the increase in pv (flow energy). Increase in potential energy of fluid is the most important change found in almost all pump applications.

Nozzles

Nozzles are devices which increase the velocity of a fluid at the expense of pressure. A typical nozzle used for fluid flow at subsonic* speeds is shown in Figure 3.7.

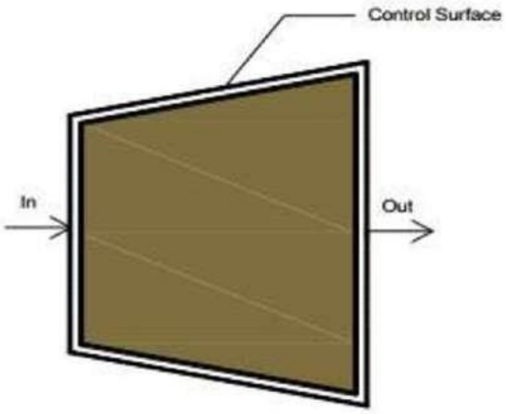
General Assumptions

1. In nozzles fluids flow at a speed which is high enough to neglect heat lost or gained as it crosses the entire length of the nozzle. Therefore, flow through nozzles can be regarded as adiabatic. That is =0.

2. There is no shaft or any other form of work transfer to the fluid or from the fluid; that is □

□ =0.

Changes in the potential energy of the fluid are negligible.

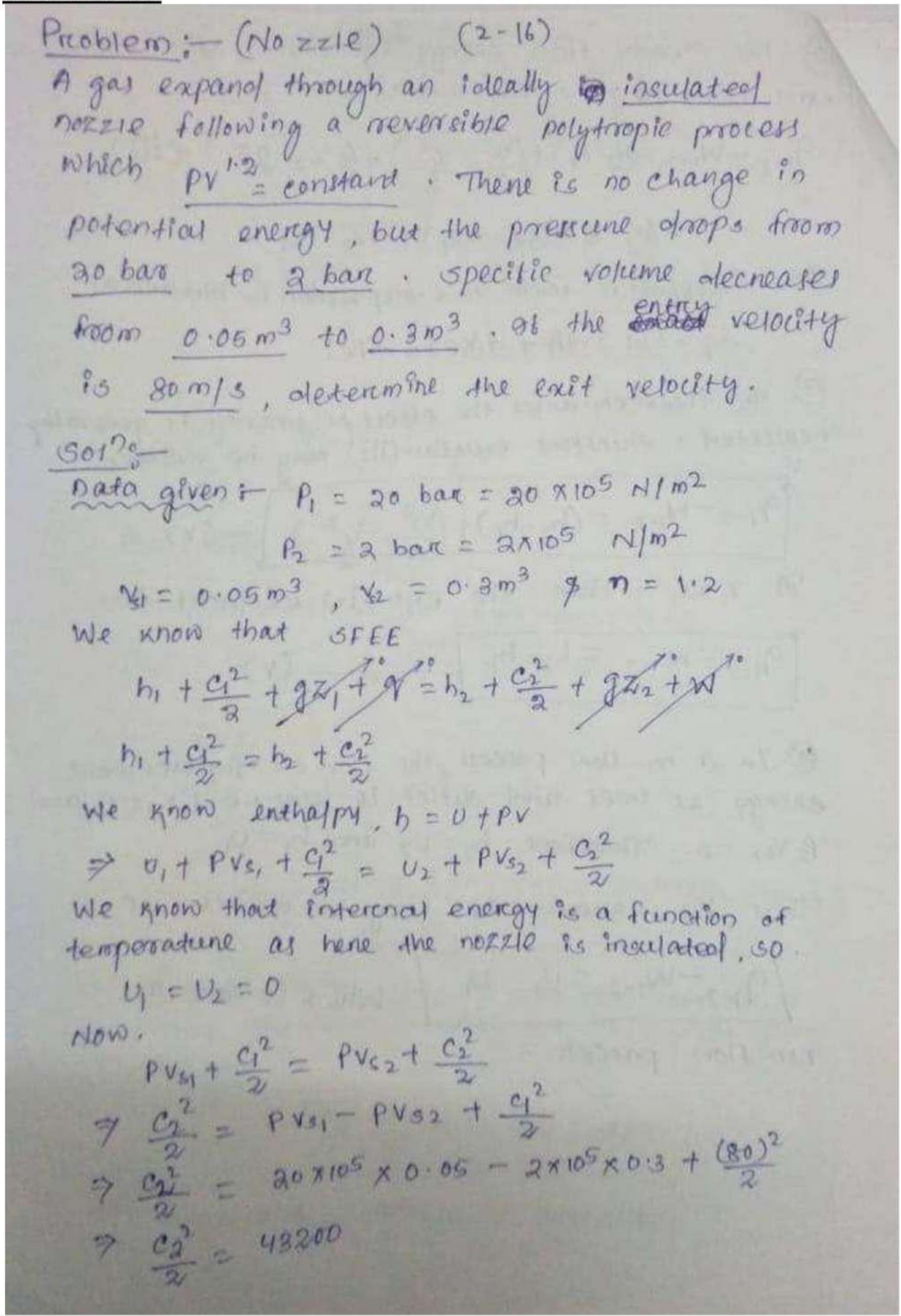


Governing Equation

$$\left[(h_2 - h_1) + \left(\frac{C_2{}^2 - C_1{}^2}{2}\right)\right] = 0$$

$$\left(\frac{C_2{}^2 - C_1{}^2}{2}\right) = (h_1 - h_2)$$

NUMERICALS:-



Problem:— (Nozzle) (2-16)

A gas expand through an ideally insulated nozzle following a reversible polytropic process which $PV^{1.2} = \text{constant}$. There is no change in potential energy, but the pressure drops from 20 bar to 2 bar. Specific volume decreases from $0.05\,m^3$ to $0.3\,m^3$. If the ~~[illegible]~~ entry velocity is 80 m/s, determine the exit velocity.

Soln:—

Data given:— $P_1 = 20 \text{ bar} = 20 \times 10^5 \text{ N/m}^2$

$P_2 = 2 \text{ bar} = 2 \times 10^5 \text{ N/m}^2$

$V_1 = 0.05\,m^3$, $V_2 = 0.3\,m^3$ & $n = 1.2$

We know that SFEE

$$h_1 + \frac{C_1^2}{2} + \cancelto{0}{gZ_1} + \cancelto{0}{q} = h_2 + \frac{C_2^2}{2} + \cancelto{0}{gZ_2} + \cancelto{0}{W}$$

$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

We know enthalpy, $h = U + PV$

$$\Rightarrow U_1 + PV_{s_1} + \frac{C_1^2}{2} = U_2 + PV_{s_2} + \frac{C_2^2}{2}$$

We know that internal energy is a function of temperature as here the nozzle is insulated, so

$U_1 = U_2 = 0$

Now,

$$PV_{s_1} + \frac{C_1^2}{2} = PV_{s_2} + \frac{C_2^2}{2}$$

$$\Rightarrow \frac{C_2^2}{2} = PV_{s_1} - PV_{s_2} + \frac{C_1^2}{2}$$

$$\Rightarrow \frac{C_2^2}{2} = 20 \times 10^5 \times 0.05 - 2 \times 10^5 \times 0.3 + \frac{(80)^2}{2}$$

$$\Rightarrow \frac{C_2^2}{2} = 43200$$

(2-17)

$\Rightarrow C_2^2 = 43200 \times 2 = 86400$

$\Rightarrow C_2 = \sqrt{86400} = \boxed{293.93 \text{ m/s}}$

<u>Problem</u>:— The velocity and enthalpy of fluid at the inlet of certain nozzle are 60m/s and 2800 KJ/Kg respectively. Then enthalpy at exit of the nozzle is 2600 KJ/Kg. The nozzle is horizontal and insulated so that no heat transfer takes place then find

(i) velocity of fluid $\frac{C_2^2}{2}$

(ii) Mass flow rate if area at inlet of the nozzle is 0.09 m² and $V_{s_1} = 0.185 \text{ m}^3/\text{Kg}$.

(iii) Exit area of the nozzle if the specific volume at the exit of the nozzle is 0.495 m³/Kg.

<u>Solⁿ</u>:— $h_1 = 2800 \text{ KJ/Kg}$, $h_2 = 2600 \text{ KJ/Kg}$

$V_{s_2} = 0.495 \text{ m}^3/\text{Kg}$, $V_{s_1} = 0.185 \text{ m}^3/\text{Kg}$

$C_1 = 50 \text{ m/s}$, $A_1 = 0.9 \text{ m}^2$

Applying SFEE

$$h_1 + \frac{C_1^2}{2} + \cancelto{0}{gz_1} + \cancelto{0}{q} = h_2 + \frac{C_2^2}{2} + \cancelto{0}{gz_2} + \cancelto{0}{W}$$

$$\Rightarrow h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

$$\Rightarrow \frac{C_2^2}{2} = \frac{C_1^2}{2} + (h_1 - h_2) = (2800 - 2600) + \frac{(50)^2}{2}$$

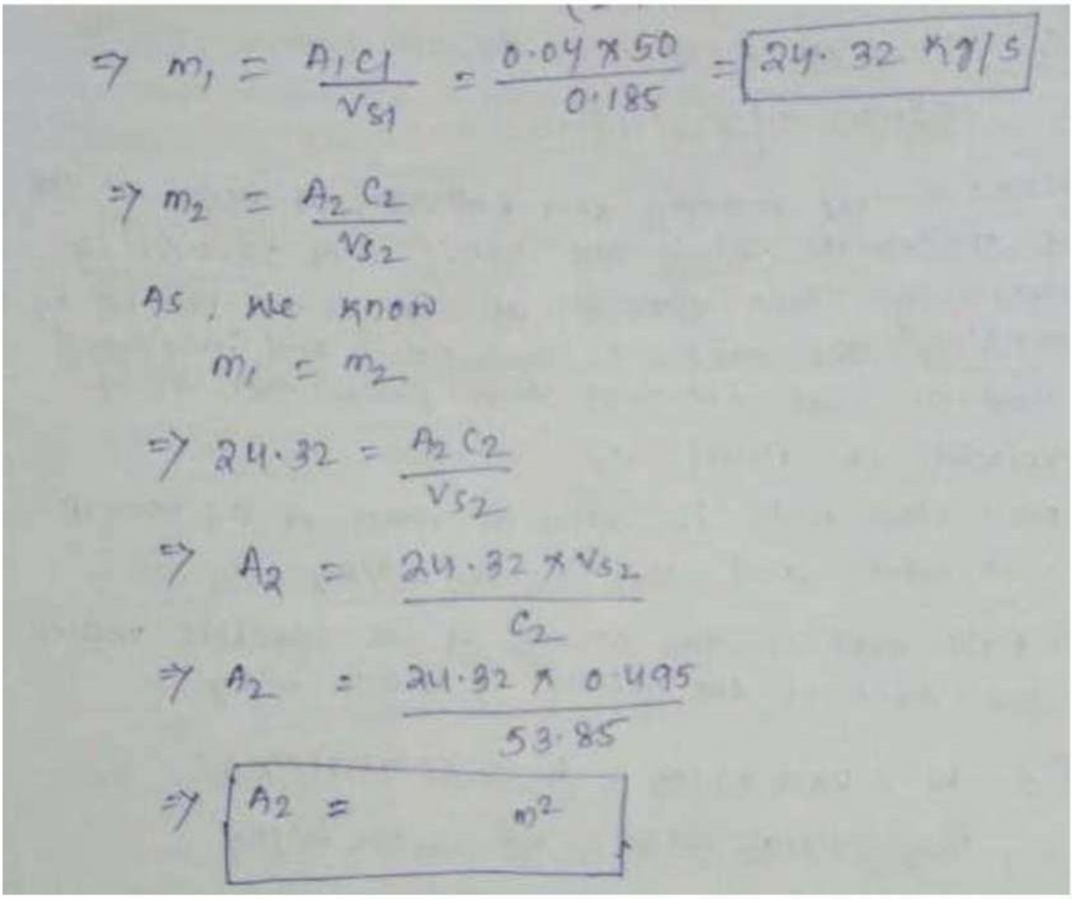
$$\Rightarrow \frac{C_2^2}{2} = 1450$$

$$\Rightarrow C_2^2 = 1450 \times 2$$

$$\Rightarrow C_2 = \sqrt{2900} = \boxed{53.85 \text{ m/s}}$$

Mass balance eqⁿ, $M_1 = M_2$

$$\frac{A_1 C_1}{V_{S_1}} = \frac{A_2 C_2}{V_{S_2}}$$



$$\Rightarrow m_1 = \frac{A_1 C_1}{V_{s1}} = \frac{0.04 \times 50}{0.185} = \boxed{24.32\ kg/s}$$

$$\Rightarrow m_2 = \frac{A_2 C_2}{V_{s2}}$$

As, we know

$$m_1 = m_2$$

$$\Rightarrow 24.32 = \frac{A_2 C_2}{V_{s2}}$$

$$\Rightarrow A_2 = \frac{24.32 \times V_{s2}}{C_2}$$

$$\Rightarrow A_2 = \frac{24.32 \times 0.495}{53.85}$$

$$\Rightarrow \boxed{A_2 = \qquad m^2}$$

Q1) The head of water at the inlet of a pipe 2000m long and 500mm diameter is 60m. A nozzle of diameter 100mm at its outlet is fitted to the pipe. FInd the velocity of water at the outlet of the nozzle if f=0.01 for the pipe.

Solution: Given:-

Head of water at inlet of pipe, H=60m

Length of pipe, L=2000m

Diameter of pipe, D=500m=0.50m

Diameter of nozzle at outlet, d=100mm=0.1m

Coefficient of friction, f=0.01

Therefore to find the velocity,

$$\frac{v^2}{2gH} = \left[\frac{1}{1 + \frac{4fL}{D} \times \frac{a^2}{A^2}} \right]$$

$$v^2 = \left[\frac{2gH}{1 + \frac{4fL}{D} \times \frac{a^2}{A^2}} \right]$$

$$v^2 = \left[\frac{2 \times 9.81 \times 60}{1 + \frac{4 \times 0.01 \times 2000}{0.5} \times \left(\frac{\frac{\pi}{4} d^2}{\frac{\pi}{4} D^2} \right)^2} \right]$$

$$v = \sqrt{\frac{2 \times 9.81 \times 60}{1 + \frac{4 \times 0.01 \times 2000}{0.5} \times \left(\frac{0.1^2}{0.5^2} \right)^2}}$$

v=30.61m/s

1. A convergent divergent adiabatic steam nozzle is supplied with steam at 10 bar and 250°c.the discharge pressure is 1.2 bar.assuming that the nozzle efficiency is 100% and initial velocity of steam is 50 m/s. find the discharge velocity.

Given Data:-

Initial pressure(p_1)=10bar Initial

Temperature(T_1)=250°c

Exit pressure(p_2)=1.2 bar

Nozzle efficiency(ηnozzle)=100%

Initial velocity of steam (v_1)=50m/s

To Find:-

Discharge velocity (v_2)

Solution:-

From steam table, For 10 bar, 250°c, $h_1=2943$ KJ/kg $s_1=6.926$ KJ/kgk

From steam table, For 1.2 bar,

$h_{f2}=439.3$ KJ/kg ; $h_{fg2}=2244.1$ KJ/kg;

$s_{f2}=1.3\ 61$ KJ/kg K ; $s_{fg2}=5.937$ KJ/kgK.

Since $s_1=s_2$,

S1=sf 2+x2sfg2

$6.926=1.361+x_2(5.937)$

$X_2=0\ .9373$

We know that,

h2=hf2+x2hfg2

= 439.3+(0.9373)2244.1

h_2 = 2542KJ/Kg

Exit velocity (V2) = Rt[(2000(2943) 2542) + 50^2]

= 896.91m/s.

2. Dry saturated steam at 6.5 bar with negligible velocity expands isentropically in a convergent divergent nozzle to 1.4 bar and dryness fraction 0.956. De termine the final velocity of steam from th e nozzle if 13% heat is loss in friction. Find th e % reduction in the final velocity.

Given data:

Exit pressure (P2) = 1.4 bar

Dryness fract ion (X2) = 0.956

Heat loss = 13%

To Find:

The percent reduction in final velocity

Solution:

From steam table for initial pressure P1 = 6.5bar, take values h_1 =

$$h_1 = 2758.8 \text{KJ/Kg}$$

Similarly, at 1.4 bar,

$$h_{fg2} = 2231.9 \text{ KJ/Kg}$$

$$h_{f2} = 458.4 \text{KJ/Kg}$$

$$h2 = hf2 + X2\ hfg2$$

$$= 458.4 + (0.956)\ 2231.6$$

$$h_2 = 2592.1 \text{ KJ/Kg}$$

Final velocity (V2) = Rt (2000(h1-h2))

$$V2 = 577.39 \text{ m/s}$$

Heat drop is 13%= 0.13

Nozzle efficiency (η) = 1- 0.13 = 0.87

Velocity of steam by considering the nozzle efficiency,

y (V2) = Rt (2000(h1-h2)) x η

$$V2 = 538.55 \text{ m/s}$$

= % reduction in final velocity = 6.72%

3.A convergent divergent nozzle receives steam at 7bar and $200^{o}c$ and it expands isentropically into a space of 3bar neglecting the inlet velocity calculat e the exit area required for a mass flow of 0.1Kg/sec . when the flow is in equilibrium through all and super saturated with $PV^{1.3}=C$.

Given Data:

Initiall pressure $(P_1) = 7bar = 7\times 10^5 N/m^2$

Initiall temperature $(T_1) = 200^oC$

Press ure $(P_2) = 3bar = 3\times 10^5 N/m^2$

Mass flow rate (m) = 0.1Kg/sec

$PV^{1.3} = C$

To Find:

Exit area

Solution:

From st eam table for P1 = 7bar and T1 = 200^oC V_1 =

0.2999

$h_1 = 2844.2$

S1 = 6.886

Similarly for P2 = 3bar

Vf2 = 0.001074 Vg2 = 0.60553 hf2 =

561.5 hfg2 = 2163.2

Sf2 = 1.672 Sfg2 = 5.319

We know that, S1 = S2 = St

$S_1 = S_{f2} + X_2 S_{fg2}$

$6.886 = 1.672 + X_2 (5.319)$ X_2 =

0.98

Similarly,

h2 = hf2 + X2 hfg2

$$h_2 = 561.5 + 0.98\,(2163.2)$$

(i) <u>Flow is in equilibriu m through all:</u>

$$V_2 = 569.56$$

$$v_2 = X_2 \times v_{g2}$$

$$= 0.98 \times 0.60553 = 0.5934$$

$$V_2 = \sqrt{2000\,(h_1 - h_2)}$$

$$V_2 = \sqrt{2000\,(2844.2 - 2681.99)}\ V_2 =$$

569.56

$$v_2 = X_2 \times v_{g2}$$

$$= 0.98 \times 0.60553 = 0.5934$$

$$m = \frac{[(A]_2 \times V_2)}{v_2}$$

$$A_2 = \frac{[m \times V_2)}{v_2} = \frac{0.5934 \times 0.1}{569.56}$$

$$A_2 = 1.041 \times 10^{-4}\,m^2$$

(ii) <u>For saturated flow:</u>

$$v_2 = \sqrt{\frac{2n}{n-1}\,(P_1 v_1)(1 - (\frac{P_2}{P_1})^{\frac{n-1}{n}}}$$

$$v_2 = \sqrt{\frac{2(1.3)}{1.3-1}\,(7 \times 10^5 \times 0.2999)\,(1 - \frac{3 \times 10^5}{7 \times 10^5})^{\frac{1.2-}{1.3}}}$$

$$v_2 = 568.69 \text{ m/s}$$

specific volume of steam at exit. For super saturated flow, $P_1 V_1^n = P_2$

$$\left(\frac{v_2}{v_1}\right)^n = \frac{P1}{P2}$$

$$\left(\frac{v_2}{v_1}\right)^n = \frac{P1}{P2}$$

$$v_2 = \left(\frac{7}{3}\right)^{\frac{1}{1.3}} \times 0.2999$$

$$v_2 = 0.5754$$

$$A_2 = \frac{(m \times V_2)}{v_2}$$

$$= \frac{0.1 \times 0.5754}{568.69}$$

$$A_2 = 1.011 \times 10^{-4} m^2$$

SECOND LAW OF THERMODYNAMICS

The **second law of thermodynamics** establishes the concept of entropy as a physical property of a thermodynamic system.

Clausius statement:-

The statement by Clausius uses the concept of 'passage of heat'. As is usual in thermodynamic discussions, this means 'net transfer of energy as heat', and does not refer to contributory transfers one way and the other.

Heat cannot spontaneously flow from cold regions to hot regions without external work being performed on the system, which is evident from ordinary experience of refrigeration, for example. In a refrigerator, heat flows from cold to hot, but only when forced by an external agent, the refrigeration system.

Kelvin statements:-

Lord Kelvin expressed the second law in several wordings.

- It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature.
- It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects.

Perpetual motion of the second kind

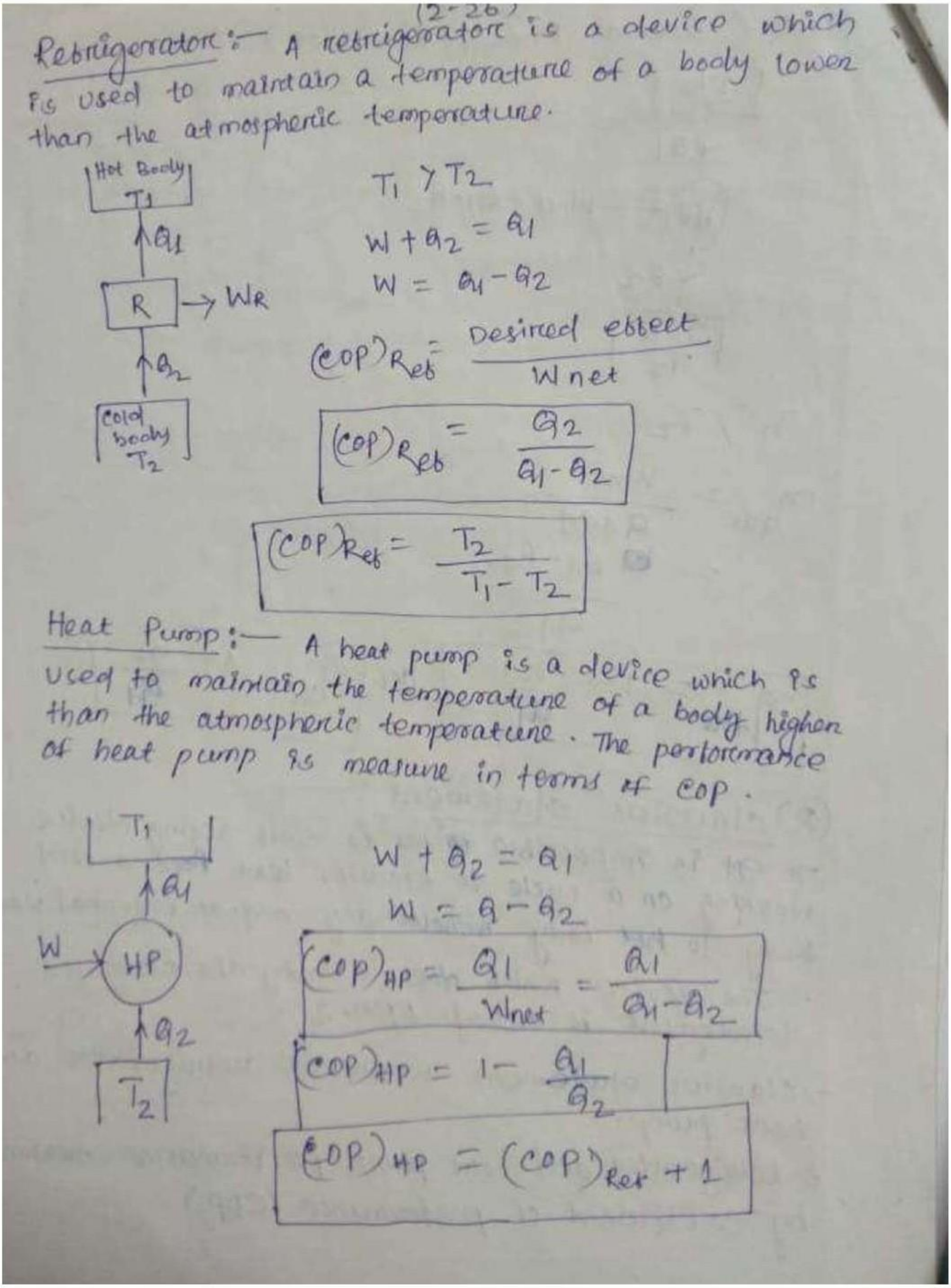
Before the establishment of the second law, many people who were interested in inventing a perpetual motion machine had tried to circumvent the restrictions of first law of thermodynamics by extracting the massive internal energy of the environment as the power of the machine. Such a machine is called a "perpetual motion machine of the second kind". The second law declared the impossibility of such machines.

Clausius inequality

The Clausius theorem (1854) states that in a cyclic process

$$\oint \frac{\delta Q}{T} \leq 0.$$

The equality holds in the reversible case and the strict inequality holds in the irreversible case, with T as the temperature of the heat bath (surroundings) here. The reversible case is used to introduce the state function entropy. This is because in cyclic processes the variation of a state function is zero from state functionality.



(2-26)

Refrigerator :- A refrigerator is a device which is used to maintain a temperature of a body lower than the atmospheric temperature.

$$T_1 > T_2$$

$$W + Q_2 = Q_1$$

$$W = Q_1 - Q_2$$

$$(COP)_{Ref} = \frac{\text{Desired effect}}{W_{net}}$$

$$\boxed{(COP)_{Ref} = \frac{Q_2}{Q_1 - Q_2}}$$

$$\boxed{(COP)_{Ref} = \frac{T_2}{T_1 - T_2}}$$

Heat Pump :- A heat pump is a device which is used to maintain the temperature of a body higher than the atmospheric temperature. The performance of heat pump is measure in terms of COP.

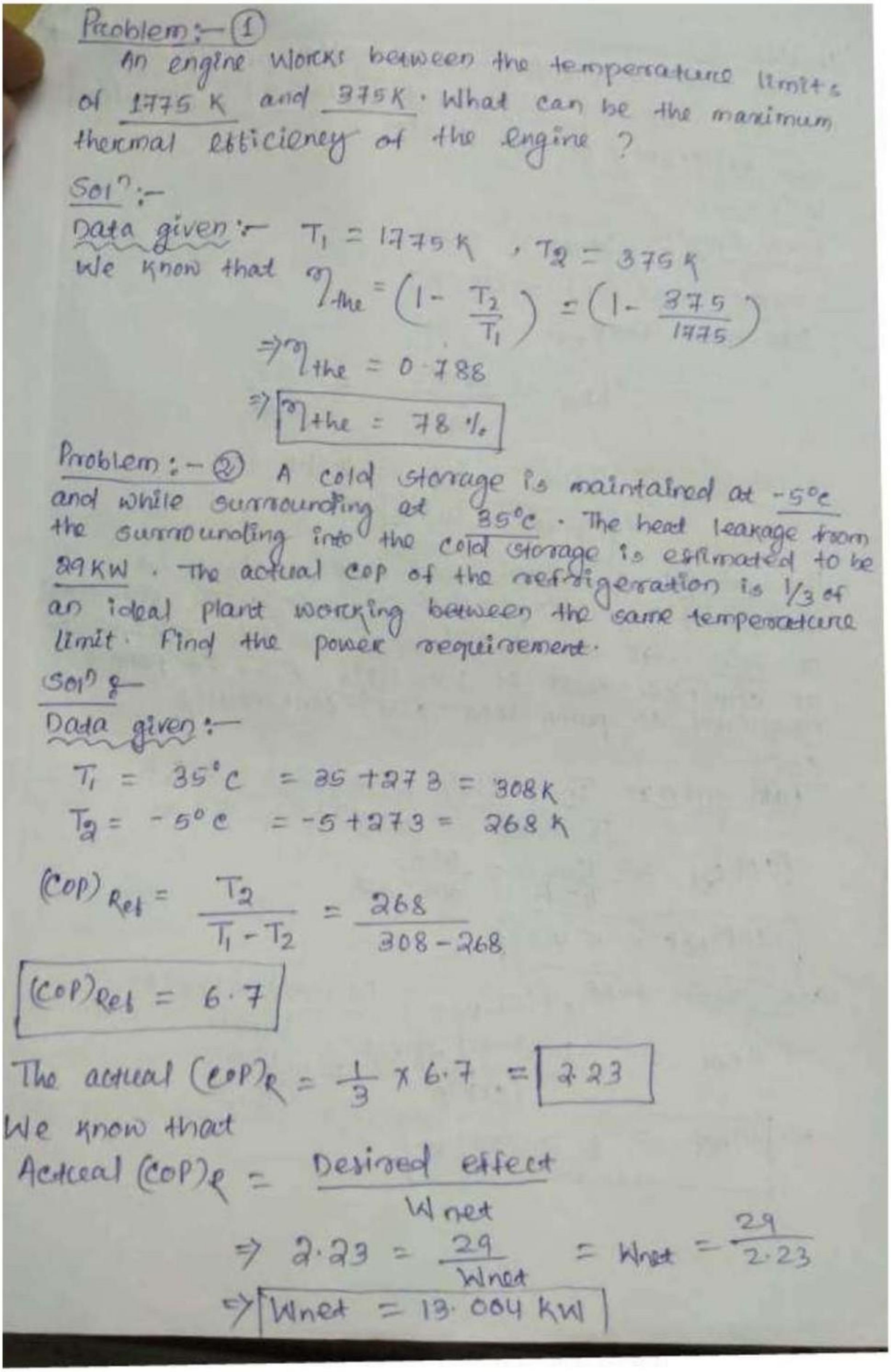
$$W + Q_2 = Q_1$$

$$W = Q - Q_2$$

$$\boxed{(COP)_{HP} = \frac{Q_1}{W_{net}} = \frac{Q_1}{Q_1 - Q_2}}$$

$$\boxed{(COP)_{HP} = 1 - \frac{Q_1}{Q_2}}$$

$$\boxed{(COP)_{HP} = (COP)_{Ref} + 1}$$



Problem :- ①

An engine works between the temperature limits of 1775 K and 375 K. What can be the maximum thermal efficiency of the engine ?

Solⁿ :-

Data given :- $T_1 = 1775\,K$, $T_2 = 375\,K$

We know that $\eta_{the} = \left(1 - \frac{T_2}{T_1}\right) = \left(1 - \frac{375}{1775}\right)$

$\Rightarrow \eta_{the} = 0.788$

$\Rightarrow \boxed{\eta_{the} = 78\,\%}$

Problem :- ② A cold storage is maintained at −5°c and while surrounding at 35°c. The heat leakage from the surrounding into the cold storage is estimated to be 29 KW. The actual cop of the refrigeration is 1/3 of an ideal plant working between the same temperature limit. Find the power requirement.

Solⁿ :-

Data given :-

$T_1 = 35^\circ C = 35 + 273 = 308\,K$

$T_2 = -5^\circ C = -5 + 273 = 268\,K$

$$(COP)_{Ref} = \frac{T_2}{T_1 - T_2} = \frac{268}{308 - 268}$$

$$\boxed{(COP)_{Ref} = 6.7}$$

The actual $(COP)_R = \frac{1}{3} \times 6.7 = \boxed{2.23}$

We know that

$$\text{Actual } (COP)_R = \frac{\text{Desired effect}}{W_{net}}$$

$\Rightarrow 2.23 = \frac{29}{W_{net}} \Rightarrow W_{net} = \frac{29}{2.23}$

$\Rightarrow \boxed{W_{net} = 13.004\,KW}$

Problem-⑤

The net work output of a cyclic process is 55 KN. If the heat input is 125 KJ. Deteremine the efficiency of the cycle.

Soln:-

Data given :- $W_{net} = 55 \text{ KN}$

input heat $(Q_1) = 125 \text{ KJ}$

We know that,

$$\eta_{the} = \frac{W_{net}}{Q_{in}} = \frac{55}{125}$$

$$\Rightarrow \eta_{the} = \frac{55}{125} = 0.44$$

$$\Rightarrow \boxed{\eta_{the} = 44\%}$$

Problem-④

A domestic food freezere is to be maintained at a temperature of -15°c. The air temp. of 30°c. If the heat leakage into the freezere of at continious rate of 1.75 KJ/s. Find the power required to pump heat out continously.

Soln:-

Data given:- $T_2 = -15^\circ c = -15 + 273 = 258 \text{ K}$

$T_1 = 30^\circ c = 30 + 273 = 303 \text{ K}$

$$(COP)_{Ref} = \frac{T_2}{T_1 - T_2} = \frac{258}{303 - 258}$$

$$\boxed{(COP)_{Ref} = 5.733}$$

We know that, $(COP)_{Ref} = \frac{\text{Desired effect}}{W_{net}}$

$$\Rightarrow W_{net} = \frac{\text{Desired effect}}{(COP)_R} = \frac{1.75}{5.73}$$

$$\Rightarrow \boxed{W_{net} = 0.305 \text{ KJ/sec}}$$

UNIT- III

PROPERTIES PROCESS OF PERFECT GAS

A perfect gas (or an ideal gas) may be defined as a state of a substance, whose evaporation from its liquid state is complete. It may be noted that if its evaporation is partial, the substance is called vapor. A vapor contains some particles of liquid in suspension. The behavior of superheated vapors is similar to that of a perfect gas.

The physical properties of a gas are controlled by the following three variables :

1. Pressure exerted by the gas,
2. Volume occupied by the gas, and
3. Temperature of the gas.

The behavior of a perfect gas, undergoing any change in these three variables, is governed by the following laws :

1. Boyles law. This law was formulated by Robert Boyle in 1662. It states, "The absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temperature remains constant." Mathematically,
PV=Constant
The more useful form of the above equation is :

$p1v1 = p2v2 = p3v3 = .. = Constant$

where suffixes 1, 2 and 3 refer to different sets of conditions.

2. Charles' law. This law was formulated by a Frenchman Jacques A.C. Charles in about 1787. It may be stated in two different forms :

(i) "The volume of a given mass of a perfect gas varies directly as its absolute temperature, when the absolute pressure remains constant." Mathematically,

$V/T=V_1/T_1=V_2/T_2=Constant$

where suffixes 1, 2 and 3 refer to different sets of conditions.

(ii) "All perfect gases change in volume by 1 / 273 th of its original volume at 0° C for every 1° C change in temperature, when the pressure remains constant."

Let
Vo = Volume of a given mass of gas at 0° C, and
Vt = Volume of the same mass of gas at t° C.

Then, according to the above statement,

where

T = Absolute temperature corresponding to t° C.
To = Absolute temperature corresponding to 0° C.

A little consideration will show, that the volume of a gas goes on decreasing by 1/ 273th of its original volume for every 1°C decrease in temperature. It is thus obvious, that at a temperature of — 273° C, the volume of the gas would become zero. The temperature at which the volume of a gas becomes zero is called absolute zero temperature.

3. Gay Lussac law. This law states, "The absolute pressure of a given mass of a perfect gas varies directly as its absolute temperature, when the volume remains constant." Mathematically

P/T=Constant

where suffixes 1, 2 and 3.... refer to different sets of conditions.

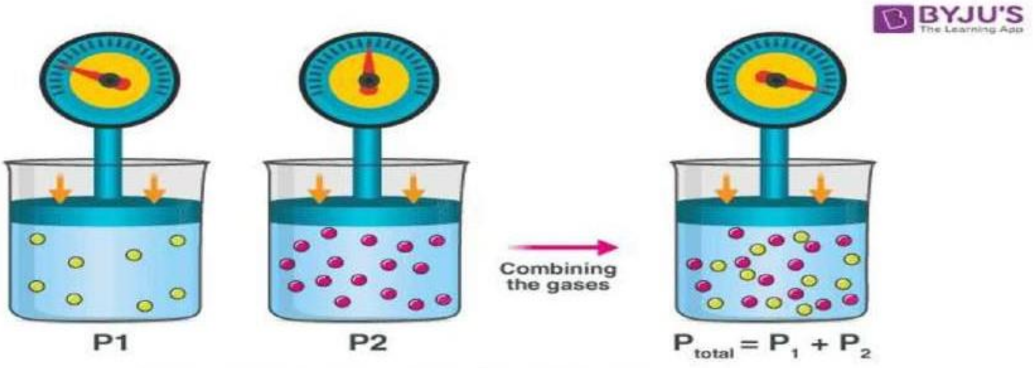
4.Avogadro's law, a statement that under the same conditions of temperature and pressure, equal volumes of different gases contain an equal number of molecules. This empirical relation can be derived from the kinetic theory of gases under the assumption of a perfect (ideal) gas. The law is approximately valid for real gases at sufficiently low pressures and high temperatures.

The specific number of molecules in one gram-mole of a substance, defined as the molecular weight in grams, is $6.02214076 \times 10^{23}$, a quantity called Avogadro's number, or the Avogadro constant. For example, the molecular weight of oxygen is 32.00, so that one gram-mole of oxygen has a mass of 32.00 grams and contains $6.02214076 \times 10^{23}$ molecules.

The volume occupied by one gram-mole of gas is about 22.4 litres (0.791 cubic foot) at standard temperature and pressure (0 °C, 1 atmosphere) and is the same for all gases, according to Avogadro's law.

5. Dalton's Law of partial pressure

Dalton's law of partial pressures is a gas law which states that the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures exerted by each individual gas in the mixture. For example, the total pressure exerted by a mixture of two gases A and B is equal to the sum of the individual partial pressures exerted by gas A and gas B (as illustrated below).



Dalton's Law of Partial Pressures

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Dalton's Law Formula

Dalton's law of partial pressures can be mathematically expressed as follows:

$$P_{total} = \sum ni=1pi \sum i=1npi \text{ (or) } P_{total} = P_1 + P_2 + P_3 + \ldots + P_n$$

Where,

- P_{total} is the total pressure exerted by the mixture of gases
- $P_1, P_2, \ldots, P_n$ are the partial pressures of the gases 1, 2,…, 'n' in the mixture of 'n' gases

Characteristics Gas Equation

The Ideal gas law is the equation of state of a hypothetical ideal gas. It is a good approximation to the behaviour of many gases under many conditions, although it has several limitations. The ideal gas equation can be written as

PV = nRT

Where,

- P is the pressure of the ideal gas.
- V is the volume of the ideal gas.
- n is the amount of ideal gas measured in terms of moles.
- R is the **universal gas constant**.
- T is the temperature.

According to the Ideal Gas equation-

The product of Pressure & Volume of a gas bears a constant relation with the product of Universal gas constant and the temperature.

i.e. pv=nRT

Universal gas constant

Let us consider the pressure exerted by the gas to be '**p,**'

The volume of the gas be – '**v**'

Temperature be – **T**

n – be the number of moles of gas

Universal gas constant – **R**

According to **Boyle's Law**,

At constant **n** & **T,** the volume bears an inverse relation with the pressure exerted by a gas.

i.e. v∝$_{1p}$v∝1p ………………………………(i)
According to Charles' Law,

When **p** & **n** are constant, the volume of a gas bears a direct relation with the Temperature.

i.e. v∝Tv∝T ………………………………(ii)
According to Avogadro's Law,

When **p** & **T** are constant, then the volume of a gas bears a direct relation with the number of moles of gas.

i.e. v∝nv∝n ………………………………(iii)
Combining all the three equations, we have-

v∝$_{nTp}$v∝nTp

or pv=nRT
pv=nRT
where **R** is the **Universal gas constant**, which has a value of 8.314 J/mol-K

MAYER'S FORMULA(Relation between C_p,C_v and R)

Consider one mole of an ideal gas. Let dQ be the amount of heat is given to the system to raise the temperature by dT, and change in internal energy be dV.

Then, from first law of Thermodynamics,

dQ = dU + PdV …(1) If heat is supplied to one mole at constant volume, i.e., V = constant, then, dV = 0 From equation (2), dQ = dU …(3) Molar specific heat (CV) at constant volume,

$$C_V = \left(\frac{dQ}{dT}\right)_V$$

From equation (4),

dQ = dU = Cv dT …(5)

If one mole of gas is supplied heat at constant pressure, i.e., from equation (3) of molar specific heat Cp at constant pressure

$$C_P = \left(\frac{dQ}{dT}\right)_P$$

or, $$dQ = C_P\,dT$$

From equation

$$dQ = C_P\,dT = dU + PdV$$

Again, from equation (2)substituting

$$dU = C_V\,dT$$

$$C_P\,dT = C_V\,dT + PdV \quad .....(4)$$

For one mole of gas ($\mu = 1$), from ideal gas equation,

$$PV = RT$$

$$P\,dV = R\,dT$$

From equations

$$(C_P - C_V)\,dT = R\,dT$$

or $$C_P - C_V = R$$

The above expression is called Mayer's relation where R = 8.31 J.mol-1 K-1. This relation is for one mole of gas.

FREE EXPANSION:-

The **Joule expansion** (also called **free expansion**) is an irreversible process in thermodynamics in which a volume of gas is kept in one side of a thermally isolated container (via a small partition), with the other side of the container being evacuated. The partition between the two parts of the container is then opened, and the gas fills the whole container.

Ideal gases

If the gas is ideal, both the initial (T_i, P_i, V_i) and final (T_f, P_f, F_f) conditions follow the Ideal Gas Law, so that initially

$$P_iV_i=nRT_i$$

and then, after the tap is opened,

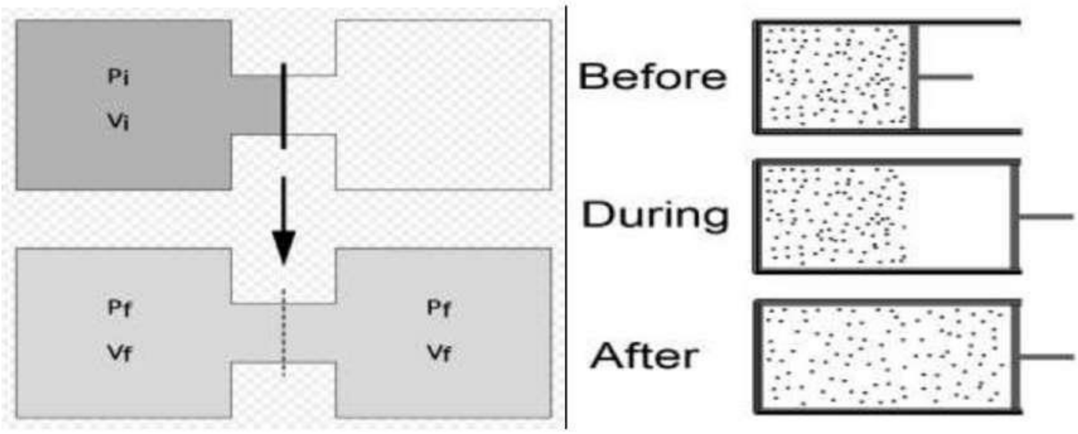
$$P_fV_f=nRT_f$$

Here n is the number of moles of gas and R is the molar ideal gas constant. Because the internal energy does not change and the internal energy of an ideal gas is solely a function of temperature, the temperature of the gas does not change; therefore $T_i=T_f$. This implies that

$$P_iV_i = P_fV_f=nRT_i$$

Therefore if the volume doubles, the pressure halves.

The fact that the temperature does not change makes it easy to compute the change in entropy of the universe for this process.



Throttling Process

This is an expansion process at constant enthalpy.

That it exists in refrigeration and air-conditioning. The LIQUID throttles in the expansion valve.

Liquefaction of gases uses this process.

Throttling is an irreversible process.

No work is obtainable with decrease of pressure. Thus, it is an useless process. It is a compulsion in refrigeration and in the liquefaction of gases. A turbine is not usable for this expansion because of phase change in throttling. The amount of work obtained will also be extremely small.

Mathematically

$dq=0$

$dw=0$

$dh=0$

$h=\text{constant}$

T changes
u= Internal energy changes.

Joule –Thomson Coefficient 'μ' involves throttling.

$\mu =(\partial T/\partial P)_{h = C}$

That μ can be positive (+).

Thus μ can have zero value.

Also μ can be negative (-).

In case of a gas, μ links to the maximum inversion temperature of a gas.

Table below contains the values of maximum inversion temperatures for few gases.

TABLE: IMPORTANT PROPERTIES OF GASES

	N.B.P. ^{0}C	Freezing Point ^{0}C	Critical Temperature ^{0}C	Maximum inversion Temp. ^{0}C
Air	-191	-212.3	-140.2	330
O_2	-183	-218.8	-118.8	620
N_2	-196	-210	-147.0	347.8
H_2	-252.8	-259.2	-239.9	-77.8
He	-268.9	-269.7	-267.9	-250.0
CO_2	-78.3	——	31.1	1230

Throttling has three possibilities.

Case 1

Temperature of gas is lower than the maximum inversion temperature

On expansion (throttling), temperature of the gas will decrease. Cooling occurs on expansion.

μ is positive.

In an expansion, there is decrease of pressure. Here it causes decrease in temperature making μ as positive.

It exists in refrigeration and air conditioning.

Case 2

Temperature of gas equals maximum inversion temperature before expansion

On expansion (throttling), no change of temperature will occur. No heating and no cooling.

$\mu = 0$

No such case exists in actual practice.

Case 3

Temperature of gas above the maximum inversion temperature before expansion

On expansion (throttling), temperature will rise. Heating on expansion

$\mu=$ — (negative)

It exists in hydrogen or helium liquefaction.

Since the maximum inversion temperature of hydrogen is -77.8^0 C.
Whereas maximum inversion temperatures of Helium is -250^0 C.

UNIT IV

INTERNAL COMBUSTION ENGINE

Heat engine:

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types-

(a) External combustion engine (b) Internal combustion engine

External combustion engine:

In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle.

Examples:

*In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work.

*In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.

Internal combustion engine:

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force. It can be classified into the following types:

1. According to the basic engine design- (a) Reciprocating engine (Use of cylinder piston arrangement), (b) Rotary engine (Use of turbine)

2. According to the type of fuel used- (a) Petrol engine, (b) diesel engine, (c) gas engine (CNG, LPG), (d) Alcohol engine (ethanol, methanol etc)

3. According to the number of strokes per cycle- (a) Four stroke and (b) Two stroke engine

4. According to the method of igniting the fuel- (a) Spark ignition engine, (b) compression ignition engine and (c) hot spot ignition engine

5. According to the working cycle- (a) Otto cycle (constant volume cycle) engine, (b) diesel cycle (constant pressure cycle) engine, (c) dual combustion cycle (semi diesel cycle) engine.

6. According to the fuel supply and mixture preparation- (a) Carburetted type (fuel supplied through the carburettor), (b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition).

7. According to the number of cylinder- (a) Single cylinder and (b) multi-cylinder engine

8. Method of cooling- water cooled or air cooled

9. Speed of the engine- Slow speed, medium speed and high speed engine

10. Cylinder arrangement-Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines.

11. Valve or port design and location- Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging.

12. Method governing- Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine

Application- Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators.

Comparison between external combustion engine and internal combustion engine:

External combustion engine Internal combustion engine *Combustion of air-fuel is outside the engine cylinder (in a boiler) * Combustion of air-fuel is inside the engine cylinder (in a boiler) *The engines are running smoothly and silently due to outside combustion * Very noisy operated engine *Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome. * It is light and compact due to lower ratio of weight and bulk to output. *Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts. * Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used *It can use cheaper fuels including solid fuels *High grade fuels are used with proper filtration *Lower efficiency about 15-20% *Higher efficiency about 35-40% * Higher requirement of water for dissipation of energy through cooling system *Lesser requirement of water *High starting torque *IC engines are not self-starting

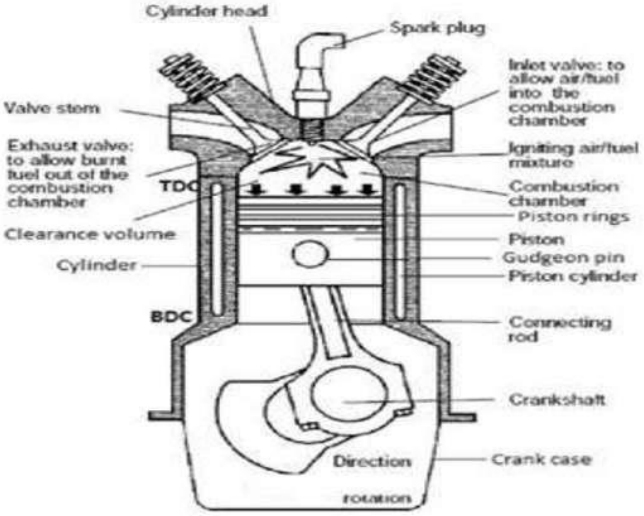
Main components of reciprocating IC engines:

Cylinder: It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above

2000 oC. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Cylinder head: The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint.

Piston: Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminium alloy which has good heat conducting property and greater strength at higher temperature.



Piston rings: These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature. 2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

Connecting rod: It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank

with crank pin. The special steel alloys or aluminium alloys are used for the manufacture of connecting rod.

Crankshaft: It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Crank case: It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.

Flywheel: It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant. It is done by storing excess energy during the power stroke, which is returned during other stroke.

Terminology used in IC engine:

1. Cylinder bore (D): The nominal inner diameter of the working cylinder.

2. Piston area (A): The area of circle of diameter equal to the cylinder bore.

3. Stroke (L): The nominal distance through which a working piston moves between two successive reversals of its direction of motion.

4. Dead centre: The position of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).

(a) Bottom dead centre (BDC): Dead centre when the piston is nearest to the crankshaft.

(b) Top dead centre (TDC): Dead centre when the position is farthest from the crankshaft.

5. Displacement volume or swept volume (Vs): The nominal volume generated by the working piston when travelling from the one dead centre to next one and given as,

$V_s = A \times L$

6. Clearance volume (Vc): the nominal volume of the space on the combustion side of the piston at the top dead centre.

7. Cylinder volume (V): Total volume of the cylinder.

$V = V_s + V_c$

8. Compression ratio (r):

Four stroke engine:

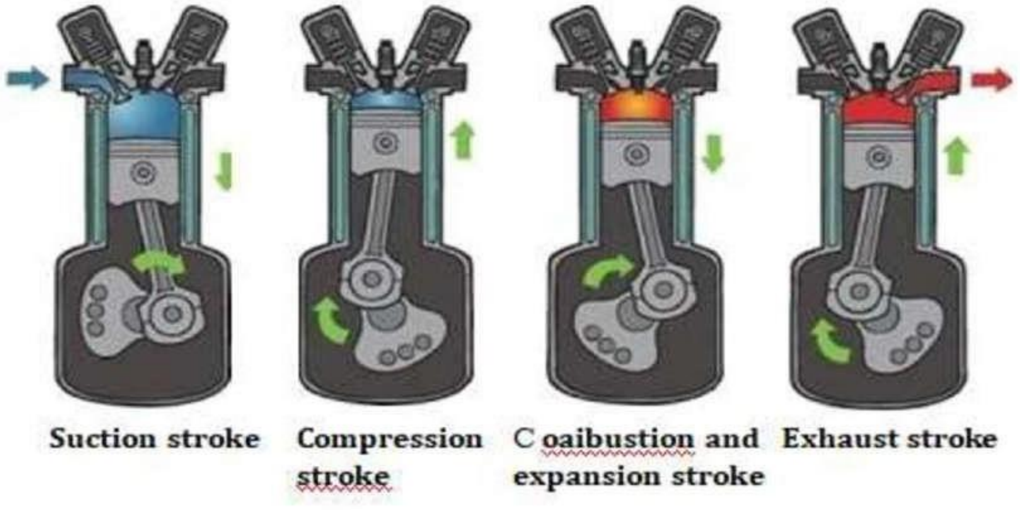
- Cycle of operation completed in four strokes of the piston or two revolution of the piston.

(i) Suction stroke (suction valve open, exhaust valve closed)-charge consisting of fresh air mixed with the fuel is drawn into the cylinder due to the vacuum pressure created by the movement of the piston from TDC to BDC.

(ii) Compression stroke (both valves closed)-fresh charge is compressed into clearance volume by the return stroke of the piston and ignited by the spark for combustion. Hence pressure and temperature is increased due to the combustion of fuel

(iii) Expansion stroke (both valves closed)-high pressure of the burnt gases force the piston towards BDC and hence power is obtained at the crankshaft.

(iv) Exhaust stroke (exhaust valve open, suction valve closed)- burned gases expel out due to the movement of piston from BDC to TDC.



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Two stroke engine:

-No piston stroke for suction and exhaust operations

-Suction is accomplished by air compressed in crankcase or by a blower

-Induction of compressed air removes the products of combustion through exhaust ports

-Transfer port is there to supply the fresh charge into combustion chamber

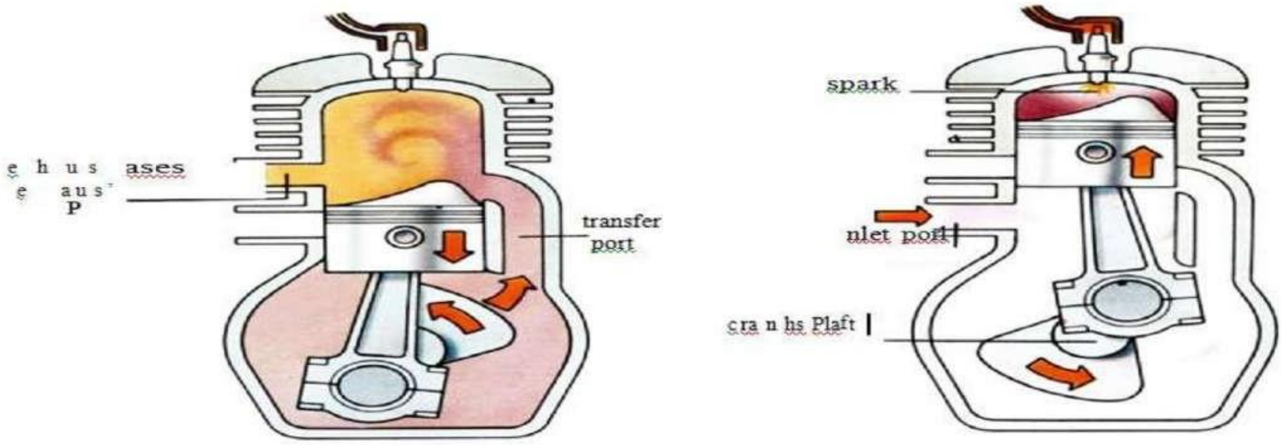


Fig. 3. Cycle of operation in two stroke engine

Comparison of Four-stroke and two-stroke engine:

Four-stroke engine Two-stroke engine

1. Four stroke of the piston and two revolution of crankshaft Two stroke of the piston and one revolution of crankshaft

2. One power stroke in every two revolution of crankshaft One power stroke in each revolution of crankshaft

3. Heavier flywheel due to non-uniform turning movement Lighter flywheel due to more uniform turning movement

4. Power produce is less Theoretically power produce is twice than the four stroke engine for same size
5. Heavy and bulky Light and compact

6. Lesser cooling and lubrication requirements Greater cooling and lubrication requirements

7. Lesser rate of wear and tear Higher rate of wear and tear

8. Contains valve and valve mechanism Contains ports arrangement

9. Higher initial cost Cheaper initial cost

10. Volumetric efficiency is more due to greater time of induction Volumetric efficiency less due to lesser time of induction

11. Thermal efficiency is high and also part load efficiency better Thermal efficiency is low, part load efficiency lesser

12. It is used where efficiency is important.

Ex-cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.

It is used where low cost, compactness and light weight are important. Ex-lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc.

Comparison of SI and CI engine:

SI engine CI engine Working cycle is Otto cycle. Working cycle is diesel cycle. Petrol or gasoline or high octane fuel is used. Diesel or high cetane fuel is used. High self-ignition temperature. Low self-ignition temperature. Fuel and air introduced as a gaseous mixture in the suction stroke. Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke. Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced. Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump. Use of spark plug for ignition system Self-ignition by the compression of air which increased the temperature required for combustion

Compression ratio is 6 to 10.5 Compression ratio is 14 to 22 Higher maximum RPM due to lower weight Lower maximum RPM Maximum efficiency lower due to lower compression ratio Higher maximum efficiency due to higher compression ratio Lighter Heavier due to higher pressures

<u>Valve timing diagram</u>:

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Fig. 4.

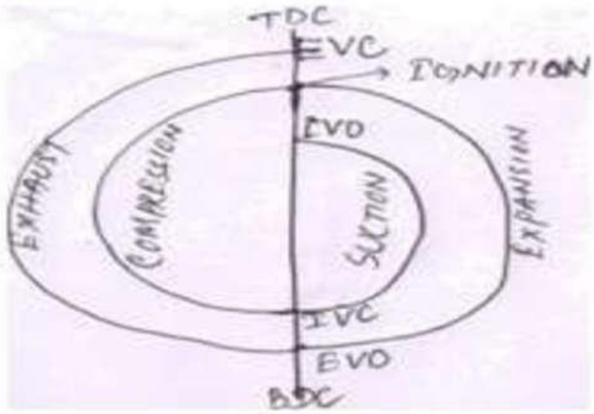


Fig. 4. Theoretical valve timing diagram

But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

Opening and closing of inlet valve

-Inlet valve opens 12 to 30° CA before TDC to facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

-Inlet valve closes 10-60° CA after TDC due to inertia movement of fresh charge into cylinder i.e. ram effect.

Figure 5 represents the actual valve timing diagram for low and high speed engine.

Fig. 5. Actual valve timing diagram for low and high speed engine

Opening and closing of exhaust valve

Exhaust valve opens 25 to 55° CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30° CA after TDC to avoid the compression of burnt gases in next cycle. Kinetic energy of the burnt gas can assist maximum exhausting of the gas. It also increases the volumetric efficiency.

Note: For low and high speed engine, the lower and upper values are used respectively

Valve overlap

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.

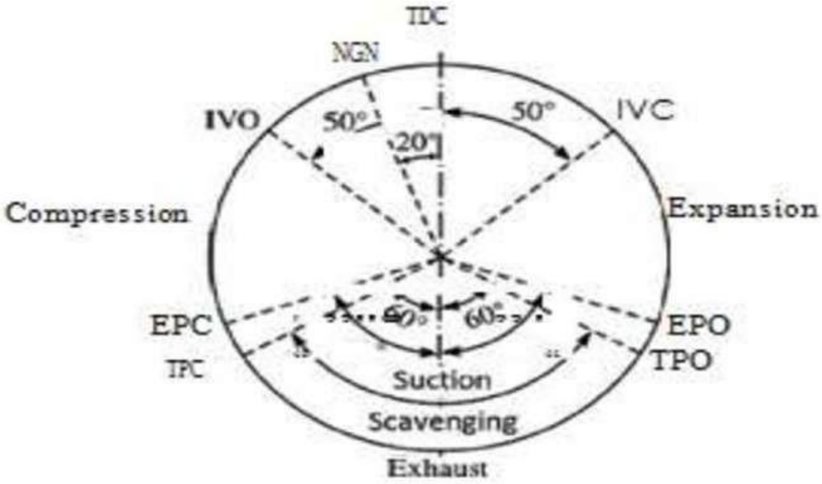
Port timing diagram:

-Drawn for 2-stroke engine

-No valve arrangement

-3 ports- inlet, transfer and exhaust

Figure 6 shows port timing diagram for 2-stroke engine



Port timing diagram for 2-stroke engine

Port timing diagram for 2-stroke engine

Working cycle:

(a) Otto cycle- thermodynamic cycle for SI/petrol engine -Reversible adiabatic compression and expansion process -Constant volume heat addition (combustion) and heat rejection process (exhaust)

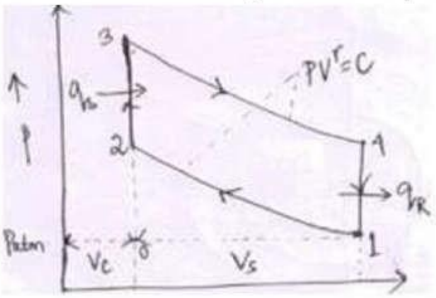
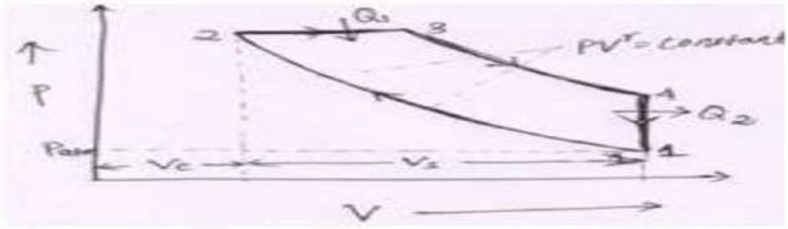


Figure 7 depicts the Otto cycle

Otto cycle

(b) Diesel cycle- thermodynamic cycle for low speed CI/diesel engine -Reversible adiabatic compression and expansion process -Constant pressure heat addition (combustion) and heat rejection process (exhaust) Figure 8 depicts the diesel cycle.



Diesel cycle

FUELS &FUEL INJECTION

In IC engines, the chemical energy contained in the fuel is converted into mechanical power by burning (oxidizing) the fuel inside the combustion chamber of the engine.

Fuels suitable for fast chemical reaction have to be used in IC engines, they are following types-

(a) Hydrocarbons fuels derived from the crude petroleum by proper refining process such as thermal and catalytic cracking method, polymerisation, alkylation, isomerisation, reforming and blending.

(b) Alternative fuels such as-Alcohols (methanol, ethanol) Natural gas (methane) LPG (propane, butane) Hydrogen

*Classification of petroleum fuels used for IC engine:

Liquid hydrocarbons- Engine fuels are mainly mixtures of hydrocarbons, with bonds between hydrogen and carbon atoms. During combustion these bonds are broken and new bonds are formed with oxygen atoms, accompanied by the release of chemical energy. Principal products are carbon dioxide and water vapour. Fuels also contain small amounts of S, O_2, N_2, H_2O. The different constituents of crude petroleum which are available in liquid hydrocarbons are- paraffins, naphthenes, naphthenes, olefins, aromatics.

(i) Paraffin-

-Paraffins or alkanes can in general be represented by-C_nH_{2n+2} -All the carbon bonds are single bonds – they are "saturated" high number of H atoms, high heat content and low density (620 – 770 kg/m3) -The carbon atoms can be arranged as a straight chain or as branched chain compounds. -Straight chain group (normal paraffins) □ shorter the chain, stronger the bond □ not suitable for SI engines – high tendancy for autoignition according to the value of "n" in the formula, they are in gaseous (1 to 4), liquid (5 to 15) or solid (>16) state.

-Hexan C_6H_{14} (normal paraffin) H H H H H H H – C – C – C – C – C – C – H H H H H H H

- Branched chain compounds (isoparaffins) When four or more C atoms are in a chain molecule it is possible to form isomers, they have the same chemical formula but different structures, which often leads to very different chemical properties.

Example: Iso-octane- C_8H_{18}

(ii) Naphthenes-

-Also called as cycloparaffins and represented as CnH2n -Saturated hydrocarbons which are arranged in a circle have stable structure and low tendancy to autoignite compared to alkanes (normal paraffins) -Can be used both in SI-engines and CI-engines -Low heat content and high density (740 – 790 kg / m3)

(iii) Olefins-

-Olefins or alkenes are represented as Mono olefins-CnH2n or Dio-olefins CnH2n-2 -Olefins have the same C-to-H ratio and the same general formula as naphthenes, their behavior and characteristics are entirely different -They are straight or branch chain compounds with one or more double bond. The position of the double bond is indicated by the number of first C atom to which it is attached, i.e., CH2=CH.CH2.CH2.CH3 called pentene-1 CH3.CH=CH3 called butene-2 -Olefinic compounds are easily oxidized, have poor oxidation stability -Can be used in SI-engines, obtained by cracking of large molecules low heat content and density in the range 620 – 820 kg / m3

Alkenes are such as, Hexen (mono-olefin) H H H H H H H – C – C – C – C – C = C - H H H H H Butadien (dio-olefin) H H H H H – C = C – C = C – H (iv) Aromatics-

-These are so called due to aromatics odour and represented as CnH2n-6 -They are based on a six-membered ring having three conjugated double bonds -Aromatic rings can be fused together to give polynuclear aromatics, PAN, also called polycyclic aromatic hydrocarbons, PAH simplest member is benzene (C6H6)

-Can be used in SI-engines, to increase the resistance to knock not suitable for CI-engines due to low cetene number -Low heat content and high density in the range 800 – 850 kg / m3

*Refinery processes:

Crude oil is the liquid part of the naturally occurring organic material composed mostly of HCs that is trapped geologically in underground reservoirs – it is not uniform and varies in density, chemical composition, boiling range etc. for different fields

(i) Distillation process

-This is the initial process used in all refineries – aims to separate the crude oil into different boiling range fractions, each of which may be a product in its own right, a blend component or feed for further processing step -Crude oil contains many thousands of different HCs, each has its own boiling point – lightest are gases at ambient temperature but can remain dissolved in heavier liquid HCs unless temperature is raised, heaviest are solids at ambient temperature but stay in solution unless temperature is lowered. Gasoline distillation temperature is 35 – 200 oC Jet fuel 35 - 150 Diesel fuel 175 – 370 Heavy fuels, oil 370 – 550

-Generally distillation of crude oil produces 30% gasoline, 20-40 % diesel fuel, 20 % heavy fuels, 10-20 % heavy oils.

(ii) Cracking process

-There are two types of cracking process for engine fuel production: thermal cracking and catalytic cracking

(a)Thermal cracking: It takes place through the creation of HC free radicals by C to - C bond scission - The feed is heated to around 500 - 600 OC and 70 - 100 bars and passed into a soaking chamber where cracking takes place. The cracked products are fractionated. The product is relatively unstable and requires the use of antioxidants and other treatments to prevent gum formation in use. It has relatively poor MON (motor octane number).

(b)Catalytic cracking: It is the most important and widely used process for converting heavy refinery streams to lighter products – to increase the ratio of light to heavy products from crude oil. -Compared to thermal cracking, it has higher yield, improved quality product for gasoline (not for diesel fuel) and superior economics. -A fluidized bed of catalyst is used – feed is introduced into it. Catalyst flows from one vessel to another through a pipe (between reactor and regenerator). Cracked oil vapour pass to fractionating towers where smaller molecules are separated from heavier products (gas, catalytic naphtha, cycle oils and residue). -Aluminium silicate known as zeolite is used as a catalyst – has high activity and suppress the formation of light olefins.

(iii)Alkylation: It is a process for producing a high-octane gasoline component (alkylate) by combining light olefins with isobutane in the presence of a strongly acidic catalyst (sulfuric or hydrofluoric acid).

(iv)Isomerization: It is a process for converting straight chain paraffins to branch chain – used to provide isobutane feed for the alkylation process or to convert relatively low-octane quality of straight paraffins to more valuable branch chain molecules.

eg. n-pentane with RON (research octane number) 62 can be converted to isopentane with RON 92

-Process involves contacting HCs with a catalyst (platinum on a zeolite base) and separating any unchanged straight paraffins for recycle through the unit. The product is clean burning and has better RON quality.

(v)Polymerization: It is a process where light olefins such as propene and butenes are reacted together to give heavier olefins which have good octane quality and low vapour pressure in gasoline. -Most commonly used catalyst is phosphoric acid -The product is almost 100 % olefinic and has relatively poor MON compared with RON.

eg. $CH_3CH_2CH=CH_2 + CH_3CH=CH_2 \rightarrow CH_3(CH_2)_4CH=CH_2$ butene propene heptene

*Alternative fuels:

(a) Alcohols: These include methanol (methyl alcohol), ethanol (ethyl alcohol), propanol (propyl alcohol), butanol (butyl alcohol) as compounds -The OH group which replaces one of the H atoms in an alkane, gives these compounds their characteristic properties -Specific heating value is lower than gasoline (42 – 43 MJ/kg) methanol (19.7 MJ/kg) and ethanol (26.8 MJ/kg) -For air-fuel mixture SHV is comperable with gasoline (MJ/kg-mixture at stoichiometric mixtures) -Other alcohol groups such as dihydric and trihydric alcohols are not used as a fuel in IC engines

(i) Methanol -Can be obtained from natural gas – has near and long-term potential -Has high octane quality (130 RON, 95 MON) -Can be used in low-concentration (5-15 %) in gasoline to increase octane number of the mixture

Problems; -Poor solubility in gasoline, toxicity, low energy content (about half of gasoline), high latent heat of vaporization and oxygen content -Contribute to poor driveability, incompatibility with some metals (ii) Ethanol -Produced from biomass -It is made from the sugars found in grains, such as: Corn, Sorghum, and Barley Other sources of sugars to produce ethanol include: Potato skins, Rice, Sugar cane, Sugar beets, Yard clippings, Bark, Switch grass etc. -Has high octane number – can be used in low–concentrations in gasoline -Most of the ethanol used in the United States today is distilled from corn -Scientists are working on cheaper ways to make ethanol by using all parts of plants and trees rather than just the grain. -About 99% of the ethanol produced in the United States is used to make "E10" or "gasohol," a mixture of 10% ethanol and 90% gasoline. -Any gasoline powered engine can use E10, but only specially made vehicles can run on E85, a fuel that is 85% ethanol and 15% gasoline

(b) Biodiesel:

-It is methyl or ethyl ester of a fatty acid produced from vegetable oil of edible or non edible types or animal fat or algae, by transesterification process using catalysts. -Has better lubricating properties and much higher cetane ratings than today's low sulfur diesel fuels. -Its addition reduces the fuel system wear. -Can be used in the pure form (B100), or may be blended with petroleum diesel in any concentration in most diesel engines for transportation purpose. -But, the engine may face problems, such as low temperature operation, less durability and drop in power. New diesel fuel injection systems, such as common rail systems are equipped with materials that are compatible with biodiesel (B100). -Biodiesel offers a substantial reduction in particulate matter (25%-50%) and a marginal increase of NOx (1%-6% when it is used as an alternative fuel in a CI engine. -The major problems associated with biodiesel are (i) poor oxidation stability, (ii) higher viscosity and density, (iii) lower calorific value, and (iv) cold flow property. -Blends of 20% and lower biodiesel can be used in diesel engines with no, or only minor modifications.

(c) Biogas:

-Produced by the anaerobic decomposition of organic materials such as cow dung and other waste such as cornhusks, leaves, straw, garbage, flesh of car cusses, poultry droppings, pig dung, human excreta, sewage and the plants specially grown for this purpose like water hyacinth, algae, certain types of grasses. Also any cellulosic organic material of animal or plant origin which is easily bio-degradable is a potential raw material for biogas production. Also produced by pyrolysis and hydrogasification methods -Contains a mixture of methane (50-60% vol), CO2 (30-45%), hydrogen (5-10%), nitrogen (0.5-7%) and small traces of other gases such as hydrogen sulphide and oxygen -It is a clean, but slow burning gas and having value between 5000 to 5500 kcal/kg or 38131 kJ/m3 -The octane rating of biogas is 130 and ignition temperature is 650 °C -Can be used to operate both compression ignition (diesel) and spark ignition (petrol) engines. CI engines can operate on dual-fuel (biogas+diesel) operation and pilot injection operation in which small quantity of diesel is required for igniting the mixture of air and biogas -80% saving of diesel oil can be achieved -Drawback of biogas is present of CO2. The engine performance can be improved by reducing the CO2 content in biogas.

(d) Hydrogen:

-Clean burning fuel and has the highest energy content per unit mass of any chemical fuels which can reduce the dependency on hydrocarbon based fuels

Production:

Most common method of producing hydrogen involves splitting water (H2O) into its component parts of hydrogen (H2) and oxygen (O). There are different methods to produce hydrogen-

i. Steam reformation or partial oxidation of hydrocarbons such as natural gas, naphtha or crude oil. It converts methane into hydrogen and carbon monoxide by reaction with steam over a nickel catalyst.

ii. Coal gasification- Hydrogen made from coal can probably be justified as a fuel for special applications where the unique characteristics of hydrogen can be put to advantage such as its weight or its non-polluting characteristics.

iii. Electrolysis- it uses electrical current to split water into hydrogen at the cathode (+) and oxygen at anode (-) [3].

iv. Thermo chemical method- it utilizes heat to achieve the chemical splitting of water to its elements without the need for intermediate electricity generation and without the need to use the extremity high temperature of 2500 °C or more.

v. Photo-electrolysis- it uses sunlight and catalysts to split water. In this method, a current is generated by exposing on or both electrodes to sunlight. Hydrogen and oxygen gases are liberated at the 2 electrodes by the decomposition of water. A catalyst may be included to facilitate the electrode process.

vi. Biological and photo-biological water splitting use sunlight and biological organisms to split water.

vii. Thermal water splitting uses a very high temperature (approximately 1000 °C) to split water.

viii. Biomass gasification uses selected microbes to break down a variety of biomass feed stocks into hydrogen.

Utilization of hydrogen gas:

Hydrogen can be utilized for the following purpose:

i. Residential use- hydrogen can be used in domestic cooking (stoves), radiant space heaters, electricity for lighting and for operating domestic appliances (e.g. refrigerator) which could be generated by means of fuel cells, with hydrogen gas at one electrode and air at other.

ii. Industrial use- hydrogen can be used as a fuel or a chemical reducing (i.e. oxygen removal) agent. It can also be used instead of coal or coal derived gases, to reduce oxide ores (iron ore) to the material (iron).

iii. Air craft application- The earliest application of liquid hydrogen fuel is expected to be in a jet air craft. Cold liquid hydrogen can be used directly or indirectly to cool the engine and the air frame surfaces of a high speed air craft.

iv. Electric power generation- It comprises the production of electricity by using hydrogen in fuel cell system. Hydrogen could also be used as a means for storing and distributing electrical energy. The objective of developing fuel cell power stations is to centralized and local generation of electricity.

v. As an alternative transport fuel- Hydrogen is tried as an alternative fuel in internal combustion engine. The stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture which is a great advantage in internal combustion engines, leading to higher engine speeds and greater thermal efficiency [2]. Hydrogen fuel used in IC engines is in automobiles, buses, trucks and farm machinery.

Methods of using Hydrogen as a fuel in CI engines

i. A mixture of fuel gas and air, with an approximately constant fuel to air ratio is introduced into the cylinder intake manifold. The engine power is controlled by varying the quantity of mixture entering the cylinder by means of throttle valve. It is not safe because the mixture is formed in the manifold.

ii. The hydrogen is injected directly into the engine cylinder through a valve under pressure and air is inducted through another intake valve. This method is safer one, since hydrogen and air are supplied separately; an explosive mixture is occurred inside the cylinder only. The engine power output is controlled by varying the pressure of hydrogen gas from about 14 atm at low power to 70 atm at high power.

iii. During the intake stroke, the hydrogen gas at normal or moderate pressure is drawn through the throttle valve into the engine cylinder whereas unthrottled air is drawn in through the intake port. The variation of engine power can be achieved with adjustment of hydrogen inlet throttle. The changes in fuel proportion as well as power is developed due to supply of un throttle air and power variation is possible because of the wide composition range over which hydrogen-air mixture can be ignited [1].

Advantages of using Hydrogen fuelled engine

i. It provides high efficiency because it utilizes a higher proportion of the energy in the fuel.

ii. The amount of carbon monoxide and hydrocarbons in the exhaust is very small since they are originating only from the cylinder lubricating oil.

iii. It can be easily available because it is produced by electrolysis of water.

iv. Fuel leakage to environment is not pollutant.

Disadvantages of using Hydrogen fuelled engine

i. Due to high heat release the combustion temperature may be high and also a level of nitrogen oxide is high. It can be reduced by reducing the combustion temperature by injecting water vapor into the cylinder from the exhaust.

ii. It requires heavy, bulky fuel storage both in vehicle and at the service station.

iii. Difficulty in refueling and possibility of detonation.

iv. Poor engine volumetric efficiency- gaseous fuel will displace some of inlet air and poor volumetric efficiency will result.

v. Fuel cost would be high at present day technology [2].

(e) Natural Gas:

-Natural gas is present in the earth and is often produced in association with the production of crude oil. Processing is required to separate the gas from petroleum liquids and to remove contaminants. First, the gas is separated from free liquids such as crude oil, hydrocarbon condensate, water and entrained solids. The separated gas is further processed to meet certain pipelines quality specifications with respect to water content, hydrocarbon dew point, heating value and hydrogen sulphide content. Generally, a gas sweetening plant removes hydrogen sulphide and other sulfur compounds

- Over 70% of the natural gas is formed by methane.

-It is Colorless, odorless and mostly constitutes methane which is a relatively unreactive hydrocarbon.

Utilization:

-Natural gas is widely used for different purposes such as space heating, electricity generation, industrial processes, agricultural, raw material for petrochemical industry, residential, commercial and utility markets

-On a gallon equivalent basis, natural gas costs less than gasoline, diesel fuel or any other alternative fuel. Natural gas currently supplies over 25% of the energy demand because of its quality.

-can either be stored on board a vehicle in tanks as compressed natural gas (CNG) at pressure of 16 to 25 bar or cryogenically cooled to a liquid state (-127 °C) as liquefied natural gas (LNG) at pressure of 70 to 120 bar. As a fuel and with a single throttle body injector it works best in an engine system. LNG is used in heavy duty vehicles where use of CNG would still entail space and load carrying capacity penalties. The fuel storage system of natural gas as LNG instead of CNG is less than half the weight and volume of CNG system. So, it can be easily transportable than CNG.

(i) CNG (Compressed Natural Gas)

-Natural gas consists of elements of compressor, some sort of compressed gas storage and dispensing unit of CNG into vehicles

-Two types of CNG refueling system- slow fill and fast fill. In slow fill system, several vehicles are connected to the output of the compressor at one time. These vehicles are then refilled over several hours of compressor operation. In fast fill systems, enough CNG is stored so that several vehicles can be refueled one after the other, just like refueling from a single gasoline dispenser

-The storage system of CNG is arranged as several tanks in cascade form. The CNG pressure in cascade is higher than the maximum storage pressure of the cylinder on the vehicle. The cascade attempts to deliver as much of its CNG to vehicles as possible before the pressure difference decreases to where the flow rate slows dramatically. A dryer should include in most CNG refueling systems to remove water vapor, impurities and hydrogen sulphide from natural gas before it is compressed. If water vapor is present then it can condense in the vehicle fuel system, causing corrosion especially if hydrogen sulphide is present. CNG driven vehicles with catalytic converter have less CO and HC emission but NOx emission is high

(ii) LPG (Liquefied Petroleum Gas)

-LPG is available in the market in two forms- one is propane and the other is butane. Propane is popular alternative fuel because of its infrastructure of pipe lines, processing facilities and storage for its efficient distribution and also it produces fewer emissions. Propane is produced as a byproduct of natural gas processing and crude oil refining

-Natural gas contains LPG, water vapor and other impurities and about 55% of the LPG is compressed from natural gas purification. LPG is a simple mixture of hydrocarbon mainly propane/propylene (C3S) and butane/ butylenes (C4S)

-Propane is an odorless, nonpoisonous gas which has lowest flammability range.

Utilization of LPG

LPG is used as a fuel in heating appliances and vehicles. It is increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons in an effort to reduce damage to the ozone layer

-In Europe, LPG is used as an alternative to electricity and heating oil (kerosene).It can also be used as power source for combined heat and power technologies (CHP). CHP is the process of generating both electrical power and useful heat from a single fuel source. This technology has allowed LPG to be used not just as fuel for heating and cooking, but also for de-centralized generation of electricity

-LPG has higher potential as an alternate fuel for IC engine.

Advantages of LPG

-Emission is much reduced by the use of LPG.

-LPG mixes with air at all temperatures.

-Uniform mixture can be supplied to all cylinders of multi-cylinder engine.

-Engine with high compression ratio (10:1) can use propane.

-There is cost saving of about 50% and longer life with LPG running engine.

Disadvantages of LPG

(i) A good cooling system is necessary because LPG vaporizer uses engine coolant to provide the heat to convert the liquid LPG to gas [2].

(ii) The weight of vehicle is increased due to the use of heavy pressure cylinder for storing LPG.

(iii) A special fuel feed system is required for LPG.

(iv) Requirement of safety device to prevent accident due to explosion of gas cylinders or leakage in the gas pipes.

(f) Producer Gas:

-Producer gas is a product of oxidation-reduction reactions of air with biomass. Biomass is chemically composed of elements C, H, O and some N and hence the oxidation results in products of combustion like CO2 and H2O. The molecules of O2 in the air oxidises C and H to produce these products. The gases which are at high temperature due to partial oxidation pass through a bed of charcoal (which is produced because of oxidation reaction itself) and the reduction reaction of these gases with carbon leads to carbon monoxide and hydrogen

-Volumetric composition of producer gas is CO (16-20%), H2 (16-18%), CO2 (8-10%) and some traces of higher hydrocarbons. Producer gas has a high percentage of N2, since air is used. So it has a low heat value. Density of producer gas is 0.9 to 1.2 kg/m3

-Producer gas is used in reciprocating engines and furnace. It needs little air to burn stoichiometrically and raise the temperature to a value of 1500 K at normal temperature and pressure. It is also used to power gas turbines (which are well-suited to fuels of low calorific value), spark ignited engines (where 100% petrol fuel replacement is possible) or diesel internal combustion engines (where 40% - 15% of the original diesel fuel) is still used to ignite the gas.

(g) Blast Furnace Gas:

It is a byproduct of melting iron ore in steel plants. It principally consists of CO and contains low heat value similar to producer gas. It consists of about 60% nitrogen, 18-20% CO2 and some amount of oxygen which are not flammable. It may be combined with natural gas or coke oven gas before combustion or a flame support with richer gas or oil is provided to sustain combustion. The auto ignition temperature of blast furnace gas is approximate 630 °C and it has Lower Explosive Limit (LEL) of 27% &Upper Explosive Limit (UEL) of 75% in an air-gas mixture at normal temperature and pressure. The gas is hazardous due to higher concentration of carbon monoxide [50].It should be cleaned properly because it contains lot of dust particles. Blast furnace gas depends upon types of fuel used and method of operating the blast furnace.

(h) Coke Oven Gas:

It is produced during the making of coke. It is also resulting from oxidation-reduction reactions of coal or coke with air and sometimes steams. It depends upon the type of coal used and operation method of oven. The composition of coke oven gas is H2 (54% vol), CH4 (24%), CO (8%), CO2 (6%) and some traces of higher hydrocarbon and nitrogen. With the application of heat the heavier hydrocarbons are cracked and volatile portion of coal is driven off and results in high composition of H2and CH4. Its heat value per cubic meter is only about one half that of natural gas and density is 0.40 kg/m3.

Different properties of fuels

a)Relative density (specific gravity)

b)Fuel composition

c)Specific heating value

d) Flash point

e)Viscosity

f)Surface tension

g)Freezing point

(a) Relative density (specific gravity): It is related to the measurement of the ratio of the weight of a given volume of fuel to the weight of the same volume of water, both at 20 OC and 101.325 kPa .For gasoline, the relative density is around 0.72 to 0.78 - which is equivalent to an API (American petroleum institute) range of 65 to 50,

ρ = 700 −800 [kg/m3], for unleaded gasoline this value is higher due to the aromatics

For diesel fuel, ρ = 830 − 950 [kg/m3]

(b) Fuel composition: C and H: carbon content of aromatics is around 89 %, and of paraffins and naphthenes is around 86 % Benzene: max allowable concentration is specified because it is highly toxic material, the level is 5 % Sulphur content: HC fuels contain free sulphur, hydrogen sulphide and other sulphur compounds which are objectionable it is a corrosive element that can corrode fuel lines, carburettor and injection pump. It will unite with oxygen to form sulphur dioxide, which in presence of water at low T, forms sulphurous acid.

-It has low ignition T, promote knock in SI engines. limited to approx 250 ppm (50 ppm is aimed for low pollutant emitting vehicles) Gum deposits: gasoline with unsaturated HCs forms gum in the engine, paraffin, naphthene and aromatic HCs also form some gum – it causes operating difficulties, sticking valves and piston rings, deposits in the manifold etc. Water: both dissolved and free water can be present in gasoline, free water is undesirable because it can freeze and cause problems. Dissolved water is usually unavoidable during manufacture. Lead: for leaded and unleaded gasoline max lead content is specified, lead causes pollution and destroys catalytic converters in the exhaust system. Manganese: used for antiknock in gasoline (MMT), max amount is specified, 0.00025 to 0.03 gMn/L Oxygenates: oxygenated compounds such as alcohols are used in gasoline to improve octane rating. In USA gasohol (10% ethanol contains 3.5% oxygen), TBA and methanol up to 3.5% oxygen methanol up to 5% volume, MTBE up to 15% are used. In EC monoalcohols and ethers with atm boiling points lower than the final atm boiling point of gasoline in the standards can be used. Higher concentrations require modifications on the vehicles - carburator or fuel injection system must be modified to compensate for the oxygen content of the fuel. Blends with 15% methanol can be used.

(C) Specific heating value: -Specific heating value, Hu is a measure of the energy content of the fuel per unit mass (kJ/kg or kcal/kg) .Gaseous fuels sp heating value is given in terms of energy content per unit volume (kJ/liter or kJ/m3, kcal/m3) -In IC engines lower heating value is given as the combustion products contain water in vapour form. For gasoline and diesel fuel Hu=42000-44000 kJ/kg or Hu=10200-10500 kcal/kg -Heating value of the combustible air-fuel mixture is a decisive factor for engine performance.

(d) Flash point: -Flash point is the lowest temperature of a sample at which the fuel vapour starts to ignite when in contact with a flame (ignition source). -Marcusson method – fuel container is slowly heated, while the fuel vapour is in contact with an open flame – T is measured -For gasoline it is 25 oC, diesel fuel 35 oC and heavy diesel 65 oC

(e) Viscosity: -Viscosity is an important parameter for CI engines, also influences fuel metering orifices since Re is an inverse function of fuel viscosity lower the viscosity, smaller the diameter of the droplets in the spray. -Below certain limits, low viscosity increases the leaks in the fuel system. It is a strong function of T – must be given at certain T values at 50 oC, 1.5 – 5.0 Engler or 0.5 to 0.6 centistokes

(f) Surface tension: -Surface tension is a parameter which effects the formation of fuel droplets in sprays -increasing the surface tension will reduce mass flow and air-fuel ratio in gasoline engines -lower the value, smaller the droplet diameter diesel fuel value is in the range of 0.023 – 0.032 N/m and for gasoline it is 0.019 – 0.023 N/m

(g) Freezing point: The precipitation of paraffin crystals in winter can lead to clogged filters. It can be prevented by either removing paraffins from the fuel or adding flow improvers (additives). -Antifreezing properties are determined by its filterability. -For gasoline freezing point is –65 oC and for diesel fuel –10 oC

Important fuel specifications for gasoline

(a) Gasoline volatility: Benzene for example has vapor pressure of 0.022 MPa at 38 OC in a closed container of 38 OC, benzene evaporates until the partial p has a value of 0.022 MPa, If T is raised to 80.5 OC, then saturation p will be 0.1 MPa and will be constant during the boiling For gasoline it is not possible to indicate a single value of evaporation T or vapor pressure. Gasoline contains large number of compounds - up to about 400 It has a smooth distillation curve - with good fractionation efficiency .

Low fractionation efficiency effects engine performance at different operating conditions: If distillation curve is displaced downward, gasoline becomes more volatile - poor hot start, vapor lock, high evaporative losses .

Gasoline distillation curve: Gasoline having boiling point up to 70 OC controls ease of starting and hot weather problems such as vapor lock Mid-range controls the driving in cold weathers, particularly at warm up period of engine. It also influences the ice forming in carburetor. Back end of the curve contains all the heavier, high boiling point compounds and these have high heat content - they are important in improving fuel economy for fully warmed up engine. Some of the heavier compounds may pass into the crankcase and dilute the crankcase oil. They are not readily combusted as the lighter compounds - cause combustion chamber deposits.

Distillation curve %10 evaporation point should be at low T for start up at cold temperatures - at hot weathers this may cause problems - vapor lock. 50% evaporation should be slightly above 100 OC at summer and slightly below 100 OC at winter. For warmed up engine conditions this point is not important. 90% evaporation must not be high - produces fuel film on intake manifold walls and dilutes lubricating oil. Back end of the curve must not exceed 215 OC. Gasoline volatility should be arranged according to weather conditions -particularly ambient T. Altitude has some minor effect due to pressure changes. It is also effected by the characteristics of the vehicle itself (drivability, fuel system design etc).

Cold starting: For SI engines to start, A/F ratio must be within the ignitable range, ie in general must be between 7:1 to 20:1 by weight.

When the engine is cold, it is difficult to ignite lean mixtures, because fuel may not vaporize sufficiently - under these conditions the mixture is rich to bring it to ignitable range. This is done by the injection time or by the use of a choke with carburetted engines.

Measurement of gasoline volatility: Tests usually define Reid Vapour Pressure - ASTM Distillation test and Vapour/Liquid ratio. Reid vapour pressure - obtained at air-to-liquid ratio of 4:1 and temperature 37.8 oC. Fuel is filled into a metal chamber which is connected to an air chamber and that is connected to a pressure gauge. The apparatus is immersed in water bath at 37.8 oC and is shaken until constant p is obtained - Reid VP For gasoline allowable RVP is 0.7 bar in summer and 0.9 bar in winter (at 37.8 oC) ASTM Distillation procedure - distillation rate is controlled by the heat input - distillation curve is plotted (temperature vs % evaporated).

(b)Antiknock quality of gasoline: -Knock occurs when the unburnt gases ahead of flame front (the end gases) spontaneously ignite causing a sudden rise in pressure accompanied by a characteristic pinging sound – this result in a loss of power and can lead to damage the engine. -Combustion chamber shape, spark plug location, ignition timing, end gas temperatures, in cylinder gas motion, air-fuel ratio of the mixture, fuel specifications etc. effects the occurrence of knock. -Compression ratio of the engine also strongly effects knock. The higher the CR, the better the thermal efficiency - but the greater the tendency for knock to occur. -Critical compression ratio - when knock starts. So higher fuel octane quality is required. -Autoignition of the end gases causes a rapid increase of p, producing p waves which resonate in the combustion chamber at a frequency of between 5000 - 8000 Hz, depending on the geometry of the chamber Knock results in an increase of T in the cylinder and causes a severe damage to engine components like cylinder head gasket, piston, spark plugs etc.

Octane number: -In 1929 Octane scale was proposed by Graham Edgar. In this scale two paraffinic HCs have been selected as standards (PRF, primary reference fuels)- iso-octane (2-2-4 trimethyl pentane) with very high resistance to knock (arbitrary assigned a value of 100) and n-heptane with extremely low knock resistance (assigned a value of 0). -Octane number of the fuel is the volume percentage of iso-octane in a blend with n-heptane (PRF), that shows the same antiknock performance as test fuel tested in standard engine and standard conditions. -Test engine for determining Octane values, was developed by Cooperative Fuel Research Committee (CFR). It is a single cylinder, variable CR engine. -Two different test conditions specifies the Research Octane Number (RON) and the Motor Octane Number (MON) -Antiknock Index = (RON + MON) / 2 -TEL is added to the PRF to increase the ON above 100 or n-heptane is added to the sample to reduce ON below 100, then nonlinear extrapolation is applied ON can be increased by antiknock agents - at less expense than modifying HC composition by refinery process. Most effective agents are lead alkyls - TEL - tetraethyl lead, $(C_2H_5)_4Pb$ TML - tetramethyl lead,

MMT addition of about 0.8 g lead per litre, provides a gain of about 10 ON in gasoline

Important fuel specifications for diesel

(a) Viscosity: -Viscosity of a fluid indicates its resistance to flow - higher the viscosity, the greater the resistance to flow. -It may be expressed as absolute viscosity (Poise, P) or kinematic viscosity (stoke, St).

-It varies inversely with temperature, usually given at 20 - 40 OC -Fuel atomization depends on viscosity 2 - 8 mm2/s (cSt) at 20 OC -Lower the viscosity, smaller the diameter of the droplets in the spray

(b) Surface tension: -Surface tension is a parameter which effects the formation of fuel droplets in sprays -Lower the value, smaller the droplet diameter -Diesel fuel 0.023 – 0.032 N/m

(c) Cetane number: -Cetane number is used to specify the ignition quality of diesel fuel. -Running on low Cetane number will produce cold start problems. Peak cylinder pressure, combustion noise and HC emissions will increase -more fuel will be injected before ignition, less time for combustion. -Higher CN results in a sooner ignition - extremely high CN may ignite before adequate FuelAir mixing can take place - higher emissions. Power output can be reduced if burning starts too early.

Measurement of cetane number: -Cetane number is measured by comparing the "ignition delay time" of the sample fuel with a mixture of cetane (C16H34) and alphamethyl naptane (C10H7CH3). The Cetane percentage in the mixture gives the CN of the sample fuel. -CN of the reference fuel cetane is arbitraryly set at 100, and of alphamethyl naptane at 0. -CFR engine is used to measure the compression ratio at which ignition starts. CR is gradually increased while the engine is driven by an electric motor - a curve of CN vs critical CR is obtained. -Inlet air temp is 30 oC and cooling water temp is at 100 oC An easier and practical method to obtain Cetane Number is by calculating the Diesel Index. Increasing the DI, increases the tendency to ignite.

-AP is obtained by heating equal amounts of annilin and diesel fuel. While cooling down, the temp at which the annilin separates from the mixture is the AP

-Cetane number is in the range of, 50 - 60 for high speed Diesel engines 25 - 45 for low speed Diesel engines Normal Diesel fuel CN is 40 - 55

DI of 50 gives a CN of around 50

Carburetion

The process of preparing a combustible fuel-air mixture outside engine cylinder in SI engine is known as carburetion. Important factors which affect the process of carburetion are given below; -time available for the mixture preparation i.e. atomisation, mixing and the vaporisation -Temperature of the incoming air -quality of the fuel supply -design of combustion chamber and induction system

Mixture requirements for steady state operation: Three main areas of steady state operation of automotive engine which require different air fuel ratio are discussed below,

(a) Idling and low load: -from no load to about 20% of rated power -No load running mode is called idling condition -very low suction pressure give rise to back flow of exhaust gases and air leakage -

increases the amount of residual gases and hence increase the dilution effects -Rich mixture i.e. F/A ratio 0.08 or A/F ratio 12.5:1 provide smooth operation of the engine

(b) Normal power range or cruising range: -from about 20% to 75% of rated power -dilution by residual gases as well as leakage decreases, hence fuel economy is important consideration in this case -maximum fuel economy occurs at A/F ratio of 17:1 to 16.7:1 -mixture ratios for best economy are very near to the mixture ratios for minimum emissions

(c) Maximum power range: -from about 75% to 100% of rated power -mixture requirements for the maximum power is a rich mixture, of A/F about 14:1 or F/A 0.07

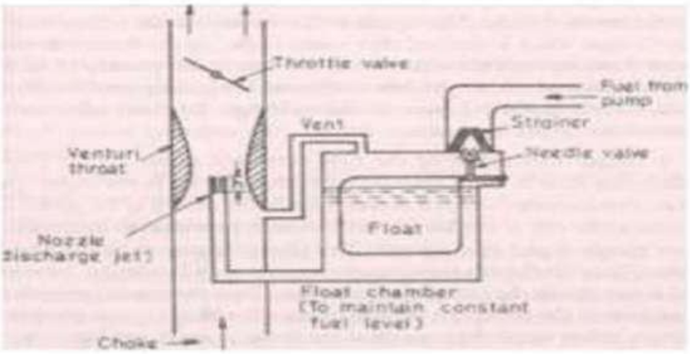
-Rich mixture also prevents the overheating of exhaust valve at high load and inhibits detonation -in multi-cylinder engine the A/F ratio are slightly lower

Mixture requirements for transient operation: Carburettor has to provide mixture for transient conditions under which speed, load, temperature, or pressure change rapidly -evaporation of fuel may be incomplete in the transient condition, quantity of fuel may be increasing and decreasing

(a) Starting and warm up requirements: -engine speed and temperature are low during the starting of the engine from cold -during starting very rich mixture about 5 to 10 times the normal amount of petrol is sulpplied i.e. F/A ratio 0.3 to 0.7 or A/F ratio 3:1 to 1.5:1 -mixture ratio is progressively made leaner to avoid too rich evaporated fuel-air ratio during warm up condition -too high volatility may form vapour bubbles in the carburettor and fuel lines particularly when engine temperatures are high -too low volatility may cause the petrol to condense on the cylinder walls, diluting and removing the lubricating oil film

(b) Acceleration requirements: - Acceleration refer to an increase in engine speed resulting from the opening of the throttle -acceleration pump is used to provide additional fuel

Simple Carburettor: -provide air-fuel mixture for all operating conditions -Carburettor depression is pressure differential in the float chamber and venture throat which causes discharge of fuel into the air stream -flow is controlled by small hole of fuel passage -pressure at the throat at the fully open throttle condition lies between 4 and 5 cm of Hg and seldom exceeds 8 cm Hg -petrol engine is quantity governed -Drawback of simple carburettor is that it provides too rich and too lean mixture due to vacuum created at the throat is too high and too small which is undesirable



simple carburettor

A simple carburettor

*Complete Carburettor: Additional systems used with simple carburettor can help the engine to operate at all conditions, which are given below,

(i) Main metering system: -provide constant fuel-air ratio at wide range of speeds and loads. -mainly based upon the best economy at full throttle (A/F ratio about 15.6:1) The different metering systems are,

Compensating jet device:-Addition to the main jet, a compensating jet is provided to provide the leanness effect .

Emulsion tube or air bleeding device: -mixture correction is done by air bleeding alone -in this arrangement main metering jet is fitted about 25 mm below the petrol level which is called as submerged jet .

Back suction control or pressure reduction method: -in this arrangement large vent line connects the carburettor entrance with the top of the float chamber and another small orifice line is connected with the top of the float chambers with venture throat -it creates pressure differences according to engine operating conditions .

Auxiliary valve carburettor: -Valve spring of auxiliary valve lift the valve during increase of engine load which increases the vacuum at venture -Allows more admittance more additional air and the mixture is not over rich .

Auxiliary port carburettor: -opening of butterfly allows more air inductance which decreases quantity of fuel drawn -used in aircraft carburettors .

(ii) Idling system: -Idling jet is added for the idling and low load operation which requires rich mixture sof about A/F ratio 12:1 -consists of small fuel line from the float chamber to a point of throttle side -gradual opening of throttle may stop the idling jet

(iii) Power enrichment or economiser system: -this system provides the richer mixture for maximum power range of operation -It has meter rod economiser of large orifice opening to the main jet as the throttle is opened beyond a certain point -rod is tapered or stepped

(iv) Acceleration pump system: -Engine acceleration condition or rapid increase in engine speed may open the throttle rapidly which will not able to provide rich mixture -acceleration pump of spring loaded plunger is used for fuel supply .

(v) Choke: -Rich mixture is required during cold starting period, at low crancking speed and before the engine warmed up condition -butterfly type valve or choke is used between the entrance to the carburettor and venture throat to meet the requirement -spring loaded by-pass choke is used in higher speeds .

Carburettor types:

(i) Open choke:Zenith, solex and carter Constant vacuum type: S.U. carburettor

(ii) updraught type Horizontal or downdraught: mixture is assisted by gravity in its oassage to the engine induction

(a) Solex carburettor: -provide ease of starting, good performance, and reliability -used in Fiat and standard cars and Willey jeep -Bi-starter is used for cold starting -well of emulsion system is used for idling and slow running condition -diaphragm type acceleration pump is used for increasing speed case

(b) Carter carburettor: -downdraft type carburettor used in jeep -has triple venture diffusing type choke in which smallest lies above the level float chamber, other two below the petrol level, one below other -multiple venturies result in better formation of the mixture at very low speeds causing steady and smooth operation at very low and high engine speed -mechanical metering method is used -choke valve is provided in the air circuit for cold starting -plunger type acceleration pump is used

(c) S.U. carburettor: -constant air-fuel ratio is maintained due to vacuum depression -has only one jet -no separate idling jet or acceleration pump -constant high velocity air across the jet may avoid the use of idling jet -jet lever arrangement provides the rich mixture in cold starting -used in many British cars and Hindustan ambassador car

Drawbacks of modern carburettor: -improper mixture proportion in multi-cylinder engine -loss of volumetric efficiency due to obstruction of flow of mixture from choke tubes, jets, throttle valve etc. -wear of carburettor parts -Freezing at low temperature -surging when carburettor is tilted or during acrobatics in aircraft -backfiring in fuel pipe line

Petrol injection: -to avoid above problem of modern carburettor, petrol injection is used like in diesel engine -petrol injected during the suction stroke in the intake manifold at low pressure -injection timing is not much critical as like in diesel engine -continuous injection and timed injection methods are used

Continuous injection: -fuel is sprayed at low pressure continuously into the air supply -amount of fuel is governed by air throttle opening -in supercharged engine, fuel injected in the form of multiple spray into the suction side of the centrifugal compressor --provide efficient atomisation of fuel and uniform mixture strength to all cylinder -higher volumetric efficiency -one fuel injection pump and one injector

Timed injection system: -similar to high speed diesel engine -components are fuel feed or lift pump, fuel pump and distributor unit, fuel injection nozzles and mixture controls -mixture controls are automatic for all engine operating conditions

(i) Multiple plunger jerk pump system: -pump with separate plunger and high injection nozzle pressure for each cylinder -100 to 300 bar pressure -measured quantity of fuel for definite time and over definite period is delivered

(ii) Low pressure single pump and distributor system: -single plunger or gear pump supply fuel at low pressure to a rotating distributor -pressure about 3.5 to 7 bar

(a) Lucas petrol injection system: -firstly used in racing car -single distributor system with novel metering device -line pressure is maintained at 7 bar -metering distributor and control unit distributes the required amount of fuel at correct time and interval -has shuttle arrangements for metering unit -in aircraft engine two injectors and spark plug provided for direct injection of fuel in combustion chamber

(b) Electronic fuel injection Fuel delivery system: -electrically driven fuel pump draws fuel from tanks to distribute -fuel and manifold pressure kept constant by pressure regulator

Air induction system: -air flow meter generate voltage signal according to air flow -cold start magnetic injection valve give good fuel atomisation and also provide extra fuel during warm up condition

Electronic control unit (ECU): -sensors for manifold pressure, engine speed and temperature at intake manifold -sensor measures operating data from locations and transmitted electrically to ECU Injection timing: -injected twice for every revolution of crank shaft -triggering of injectors

Diesel injection system: Requirements of diesel injection system: -fuel must introduce precisely defined period of cycle -amounts metered very accurately -rate of injection meet desired heat release pattern -quantities of fuel meet changing speed and load condition -good atomisation of fuel -good spray pattern for rapid mixing of fuel and air -no dribbling and after injection of fuel i.e. sharp injection -injection timing suits the speed and load requirements -distribution of fuel in multi-cylinder should uniform -weight, size and cost of fuel injection system should be less

Types of diesel injection system:

(a) Air injection system: -fuel supplied through camshaft driven fuel pump -fuel valve is also connected with high pressure airline to inject into cylinder -multi-stage compressor which supply air at a pressure of about 60 to 70 bar .Air injection system -blast air sweeps the fuel along with it -good atomisation results in good mixture formation and hence high mean effective pressure -heavy and viscous fuels are used -fuel pump require small pressure -but it is complicated due to compressor arrangement and expensive -bulky engine and low bhp -overheating and burning of valve seat

(b) Solid injection system: -Fuel directly injected to combustion chamber without primary atomisation termed as solid injection. -Also known as airless mechanical injection -2 units-pressurise and atomising unit 3 different types which are described below,

(i) Individual pump and injector or jerk pump system: -separate metering and compression pump is used for each cylinder -reciprocating fuel pump is used to meter and set the injection pressure of the fuel - heavy gear arrangements which gives jerking noise, hence name is given is jerk pump -jerk pump is used for medium and high speed diesel engines

(ii) Common rail system: -high pressure fuel pump delivers fuel to an accumulator whose pressure is constant -plunger type of pump is used -driving mechanism is not stressed with high pressure hence noise is reduced -common rail or pipe is connected in between accumulator and distributing elements - separate metering and timing elements connected to automatic injector -self-governing type

(iii) Distributor system: -fuel pump pressurises, meters and times the fuel supply to rotating distributor - number of injection strokes per cycle for the pump equals to the number of cylinder -One metering element which ensure uniform distribution

* Fuel Injectors 3 main types of fuel injectors, Blast injector: -these are superseded by mechanically operated injectors used in air injection system

Mechanically operated injector: -consist of a set of camshaft, cams and rocker gear and other cams for controlling the timing of the fuel injection Automatic injector: -consists of spring loaded needle valve and operated hydraulically by the pressure of fuel -quanity of fuel is metered by the fuel pump

Types of nozzles: (a) Depends on the type of combustion chamber, Open combustion chamber: -fuel seeks air -air swirl is created due to inclined induction port -multi-hole nozzle injects fuel at a pressure of about 200 to 300 bar to slow moving air -provide good cold starting performance and improved thermal efficiency

Pre-combustion chamber: -air velocity is very much high -single hole nozzle with 65 to 100 bar injection pressure is used -used in high speed engine due to rapid combustion -external heating device for easy starting of the engine

(b) Open and closed type of nozzle, Open type: -consists of fuel orifices and open to burner -cheap and less efficient ex- opposed piston two-stroke Junkers diesel engine Closed type: pressure drop is minimised compared to open type

(c) Different types of nozzle for different combustion chamber

(i) Single hole nozzle: -used in open combustion chamber -size of hole larger than 0.2 mm -very high injection pressure required

(ii) Multi-hole nozzle: -no. of hole varies from 4 to 18 and the size from 1.5 to 0.35 mm -injection rate is not uniform

(iii) Pintle nozzle: -a projection or pintle is provided in the nozzle to avoid weak injection and dribbling -pintle may be cylindrical or conical shape -cone angle varied from 0 to 60° -provide good atomisation and reduced penetration -fuel pressures are lower than single and multi-hole nozzle

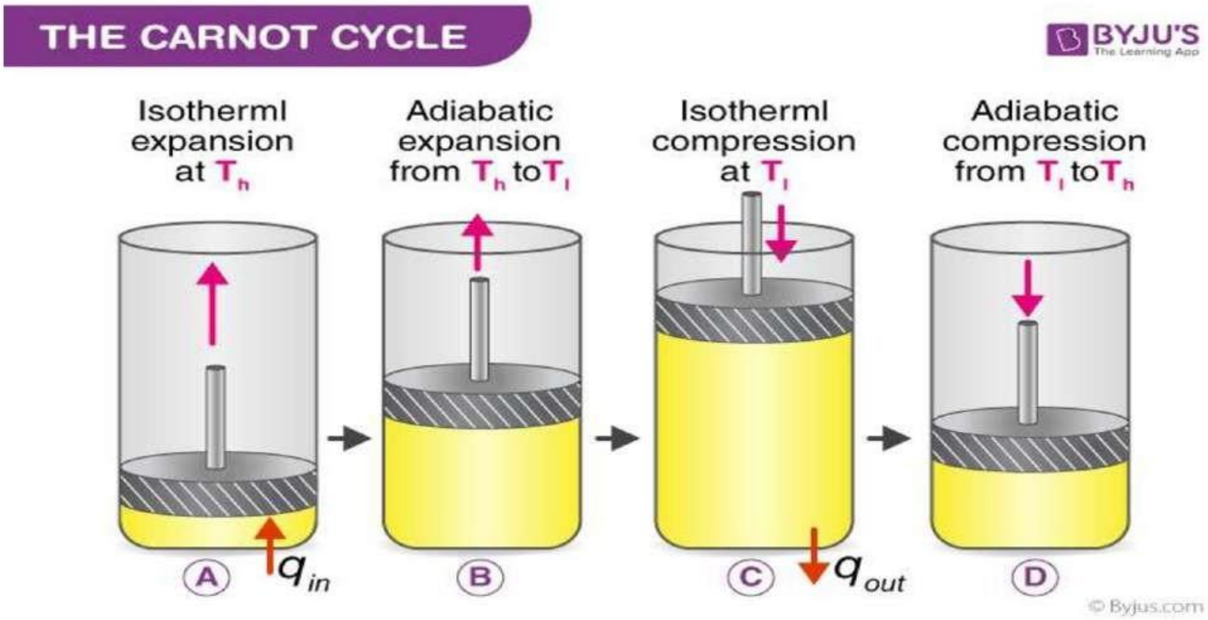
(iv) Pintaux nozzle: -injected fuel in upstream of air -development of pintle nozzle with auxiliary hole drilled in the nozzle body -reduced delay period and increased thermal efficiency

UNIT V

AIR STANDARD CYCLE

Carnot Cycle

A Carnot cycle is defined as an ideal reversible closed thermodynamic cycle. Four successive operations are involved: isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression. During these operations, the expansion and compression of the substance can be done up to the desired point and back to the initial state.



Following are the four processes of the Carnot cycle:

- In (a), the process is reversible isothermal gas expansion. In this process, the amount of heat absorbed by the ideal gas is qin from the heat source at a temperature of Th. The gas expands and does work on the surroundings.
- In (b), the process is reversible adiabatic gas expansion. Here, the system is thermally insulated, and the gas continues to expand and work is done on the surroundings. Now the temperature is lower, Tl.
- In (c), the process is reversible isothermal gas compression process. Here, the heat loss q_{out} occurs when the surroundings do the work at temperature T_l.
- In (d), the process is reversible adiabatic gas compression. Again the system is thermally insulated. The temperature again rises back to T_h as the surrounding continue to do their work on the gas.

Steps involved in a Carnot Cycle

For an ideal gas operating inside a Carnot cycle, the following are the steps involved:

Step 1:

Isothermal expansion: The gas is taken from P_1, V_1, T_1 to P_2, V_2, T_2. Heat Q_1 is absorbed from the reservoir at temperature T_1. Since the expansion is isothermal, the total change in internal energy is zero, and the heat absorbed by the gas is equal to the work done by the gas on the environment, which is given as:

$$W1 \rightarrow 2 = Q1 = \mu \times R \times T1 \times \ln v2/v1$$

Step 2:

Adiabatic expansion: The gas expands adiabatically from P_2, V_2, T_1 to P_3, V_3, T_2.

Here, work done by the gas is given by:

$$W2 \rightarrow 3 = \mu R \gamma - 1 (T1 - T2)$$

Step 3:

Isothermal compression: The gas is compressed isothermally from the state (P_3, V_3, T_2) to (P_4, V_4, T_2).

Here, the work done on the gas by the environment is given by:

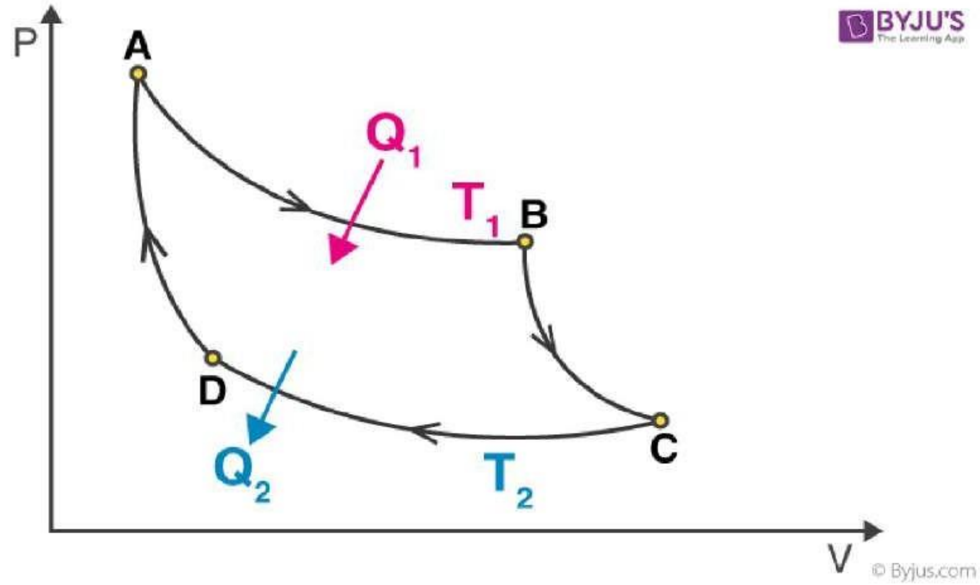
$$W3 \rightarrow 4 = \mu RT2 \ln v3v4$$

Step 4:

Adiabatic compression: The gas is compressed adiabatically from the state (P_4, V_4, T_2) to (P_1, V_1, T_1).

Here, the work done on the gas by the environment is given by:

$$W4 \rightarrow 1 = \mu R \gamma - 1 (T1 - T2)$$



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Hence, the total work done by the gas on the environment in one complete cycle is given by:

$$W = W1 \rightarrow 2 + W2 \rightarrow 3 + W3 \rightarrow 4 + W4 \rightarrow 1$$
$$W = \mu RT1 \ln v2/v1 - \mu RT2 \ln v3/v4$$
Net efficiency=Net workdone by the gas/Heat absorbed by the gas

$$\text{Netefficiency} = W/Q1 = Q1 - Q2/Q1 = 1 - Q2/Q1 = 1 - T2/T1 \ \ln v3/v4/\ln v2/v1$$
Since the step 2–>3 is an adiabatic process, we can write $T_1V_2^{Y-1} = T_2V_3^{Y-1}$

Or,

$v2/v3=(T2/T1)\ 1\gamma-1$

Similarly, for the process 4–>1, we can write

$v1/v2=(T2/T1)1\gamma-1$

This implies,

$v2/v3=v1/v2$

So, the expression for net efficiency of Carnot engine reduces to:

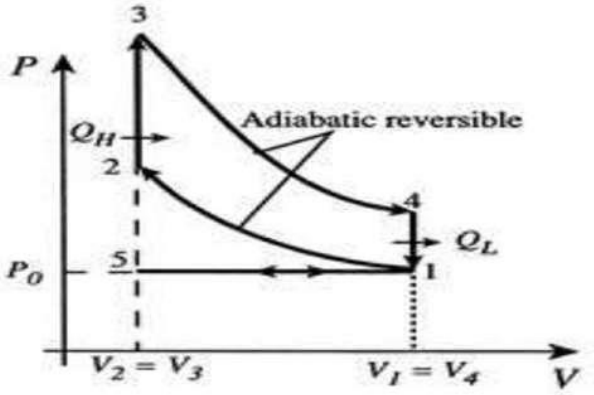
Net efficiency=1−T_2/T_1

OTTO CYCLE

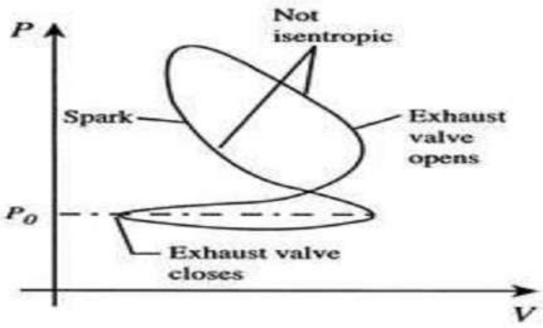
The Otto cycle is a set of processes used by spark ignition internal combustion engines (2-stroke or 4-stroke cycles). These engines a) ingest a mixture of fuel and air, b) compress it, c) cause it to react, thus effectively adding heat through converting chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of fuel and air. The different processes are shown in Figure 3.8:

1. Intake stroke, gasoline vapor and air drawn into engine ($5 \rightarrow 1$).
2. Compression stroke, p , T increase ($1 \rightarrow 2$).
3. Combustion (spark), short time, essentially constant volume ($2 \rightarrow 3$). Model: heat absorbed from a series of reservoirs at temperatures T_2 to T_3 .
4. Power stroke: expansion ($3 \rightarrow 4$).
5. Valve exhaust: valve opens, gas escapes.
6. ($4 \rightarrow 1$) Model: rejection of heat to series of reservoirs at temperatures T_4 to T_1 .
7. Exhaust stroke, piston pushes remaining combustion products out of chamber ($1 \rightarrow 5$).

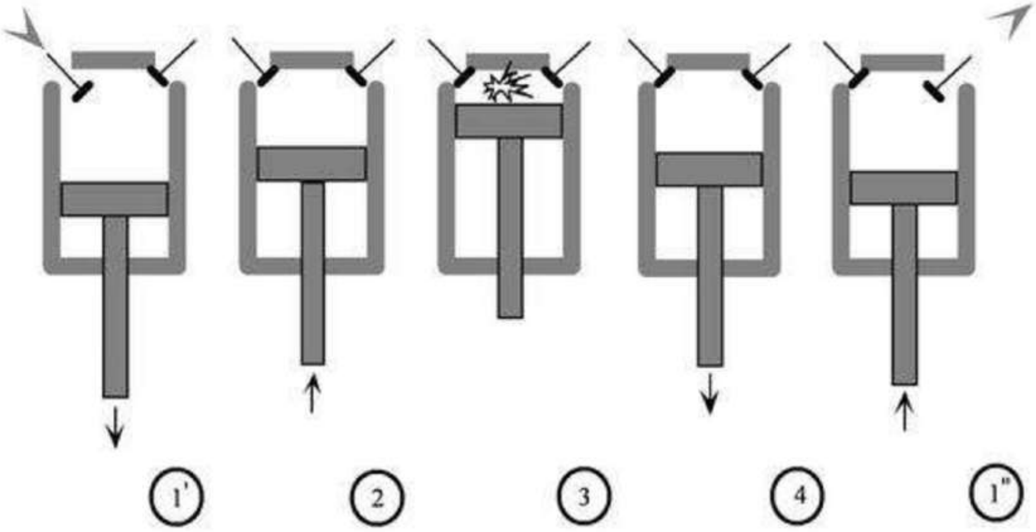
We model the processes as all acting on a fixed mass of air contained in a piston-cylinder arrangement,



The ideal Otto cycle



Sketch of an actual Otto cycle



Piston and valves in a four-stroke internal combustion engine

The actual cycle does not have the sharp transitions between the different processes that the ideal cycle has, and might be as sketched in Figure 3.9.

Efficiency of an ideal Otto cycle

The starting point is the general expression for the thermal efficiency of a cycle:

$$\eta = \frac{\text{work}}{\text{heat input}} = \frac{Q_H + Q_L}{Q_H} = 1 + \frac{Q_L}{Q_H}.$$

The convention, as previously, is that heat exchange is positive if heat is flowing into the system or engine, so Q_L is negative. The heat absorbed occurs during combustion when the spark occurs, roughly at constant volume. The heat absorbed can be related to the temperature change from state 2 to state 3 as:

$$Q_H = Q_{23} = \Delta U_{23} \qquad (W_{23} = 0)$$

$$= \int_{T_2}^{T_3} C_v dT = C_v(T_3 - T_2).$$

The heat rejected is given by (for a perfect gas with constant specific heats)

$$Q_L = Q_{41} = \Delta U_{41} = C_v(T_1 - T_4).$$

Substituting the expressions for the heat absorbed and rejected in the expression for thermal efficiency yields

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}.$$

We can simplify the above expression using the fact that the processes from 1 to 2 and from 3 to 4 are isentropic:

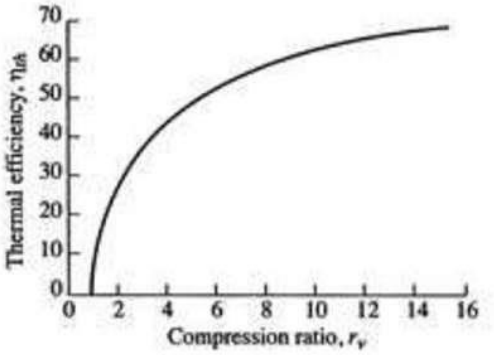
$$T_4 V_1^{\gamma-1} = T_3 V_2^{\gamma-1}, \qquad T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$(T_4 - T_1) V_1^{\gamma-1} = (T_3 - T_2) V_2^{\gamma-1}$$

$$\frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}.$$

The quantity $V_1/V_2 = r$ is called the compression ratio. In terms of compression ratio, the efficiency of an ideal Otto cycle is:

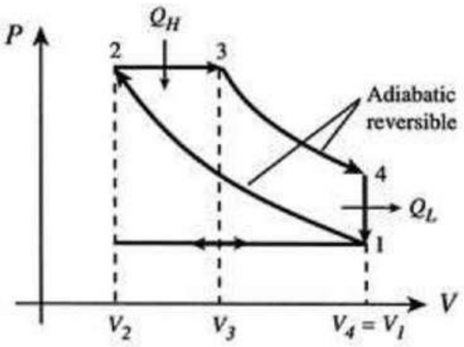
$$\eta_{\text{Otto}} = 1 - \frac{1}{(V_1/V_2)^{\gamma-1}} = 1 - \frac{1}{r^{\gamma-1}}.$$



Otto cycle thermal efficiency

Diesel Cycle

The Diesel cycle is a compression ignition (rather than spark ignition) engine. Fuel is sprayed into the cylinder at P_2 (high pressure) when the compression is complete, and there is ignition without a spark. An idealized Diesel engine cycle is shown in Figure 3.12.



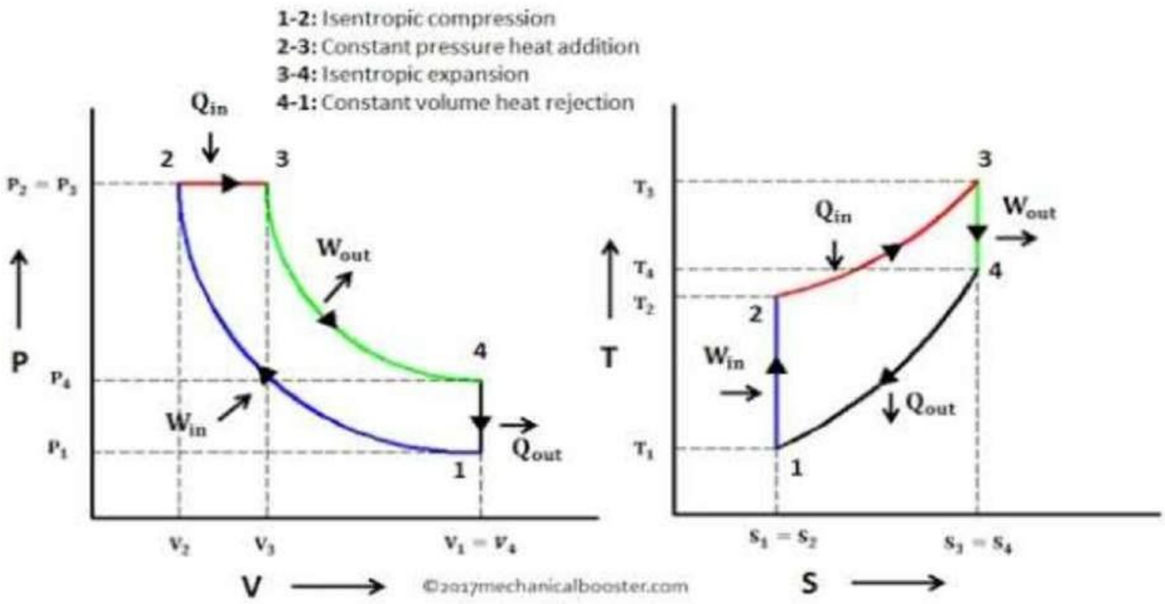
The ideal Diesel cycle

The thermal efficiency is given by:

$$\eta_{\text{Diesel}} = 1 + \frac{Q_L}{Q_H} = 1 + \frac{C_v(T_1 - T_4)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{T_1}{\gamma T_2} \frac{(T_4/T_1 - 1)}{(T_3/T_2 - 1)}.$$

The working of these four processes of Diesel cycle can be easily grasped with the help of P-V and T-S diagram.

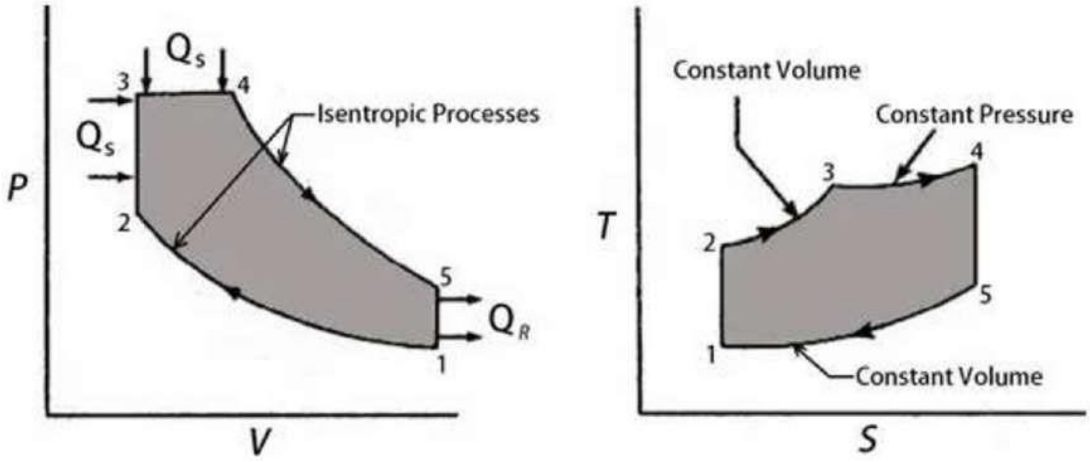


P-V and T-S Diagram of Diesel Cycle

Dual Cycle

The Otto cycle is a constant volume cycle and the Diesel cycle is a constant pressure cycle. In a practical scenario, in the constant volume cycle, the combustion might not take place at the constant volume because of the chemical reaction during the combustion need some time to take place.

Similarly, in the Constant pressure cycle, the combustion might not take place at the constant pressure because of the uncontrolled rapid combustion. So this is the difference between the air standard cycles and the practical engines. The P-V and T-S diagram for the Dual cycle is shown below.



0 → 1 and 1 → 0

When the engine is working on the full throttle, the Process 0 → 1 and 1 → 0 represents the suction and the exhaust process of Thermodynamic cycle in the P-V diagram and the effect of these two processes considered as nullified.

1 → 2

The process 1 → 2 is the isotropic compression of the air in the cylinder while piston moves from the bottom dead centre (BDC) to the top dead centre (TDC)

2 → 3 & 3 → 4

During the process, 2 → 3 First the heat is supplied at a constant volume and then the remaining part of heat will be added at the constant pressure process 3 → 4.

4 → 5 & 5 → 1

These two processes 4 → 5 & 5 → 1 will represent the isotropic expansion (Piston moves from the Top dead centre to the bottom dead centre) and the constant volume heat rejection respectively.

Thermal Efficiency

Thermodynamically, the efficiency of the Dual cycle is given by

Let, Combustion ratio, $r = \frac{V_1}{V_2}$

Pressure or explosion ratio, $\alpha = \frac{p_3}{p_2}$

Cut-off ratio $\rho = \frac{V_4}{V_3}$

Efficincy $\eta = 1 - \frac{\text{Heat rejected } (Q_{5-1})}{\text{Heat supplied } (Q_{2-3} + Q_{3-4})}$

$$\therefore \eta = 1 - \frac{mC_v(T_5 - T_1)}{mC_v(T_3 - T_2) + mC_p(T_4 - T_3)}$$

$$\therefore \eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \quad ...(i)$$

For isentropic process (1-2)

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 \cdot (r)^{\gamma-1} \quad ...(ii)$$

For constant volume process (2-3)

$\frac{T_3}{T_2} = \frac{p_3}{p_2} = \alpha$

$\therefore T_3 = \alpha T_2$

$\therefore T_3 = \alpha T_1 (r)^{\gamma-1}$ ...(iii)

$\frac{T_4}{T_3} = \frac{V_4}{V_3} = \rho$

$\therefore T_4 = \rho \cdot T_3$

i.e.. $\therefore T_4 = \rho . \alpha T_1 (r)^{\gamma-1}$ ...(iv)

For isentropic process (4-5)

T5 = T4(V5/ V4) γ−1

i.e.. $T_5 = T_4\left(\frac{\rho}{r}\right)^{\gamma-1}$

$= \left[\rho\alpha \cdot T_1 (r)^{\gamma-1}\right] \cdot \left(\frac{\rho}{r}\right)^{\gamma-1}$

$\therefore T_5 = \rho^{\gamma} \cdot \alpha \cdot T_1$ ...(v)

On substituting the values of T_2, T_3, T_4 and T_5 with the help of Equations (ii) to (v) in Equation (i), we get

$$\eta = 1 - \left[\frac{\rho^{\gamma} \cdot \alpha \cdot T - 1 - T_1}{\alpha \cdot T_1 \cdot r^{\gamma-1} - T_1 \cdot (r)^{\gamma-1}) + \gamma(\rho\alpha \cdot T_1 r^{\gamma-1} - \alpha T_1 \cdot r^{\gamma-1})}\right]$$

$$\eta = 1 - \left[\frac{(\alpha \cdot \rho^{\gamma} - 1)}{(r)^{\gamma-1}[(\alpha - 1) + \gamma \cdot \alpha(\rho - 1)]}\right] \quad ...(A)$$

Above expression shows that the efficiency increase with increasing compression ratio and decrease in cut ratio.

It can be noted from Equation A that a value of pressure ratio α > 1 results in an increased efficiency for given value of r and ρ.

Hence the efficiency of the dual cycle lies between the Otto and Diesel cycles for given value of compression ratio.

UNIT VI

Fuels and Combustion

FUEL:-A **fuel** is any material that can be made to react with other substances so that it releases energy as thermal energy or to be used for work. The concept was originally applied solely to those materials capable of releasing chemical energy but has since also been applied to other sources of heat energy such as nuclear energy

Most of the fuels contain Carbon and Hydrogen and are in solid, liquid or in gaseous form.

1. Solid Fuels (Coal): Consists of moisture, volatile matter, fixed carbon and ash. The analysis specifies on a mass basis, the relative amounts of these constituents. The ultimate analysis may be given on the dry basis.

2. Liquid Fuels: Most liquid fuels are mixtures of many different Hydrocarbons. Common examples are Gasoline, Kerosene, Diesel oil etc. Commonly a liquid fuel is treated as a single hydrocarbon with an empirical formula C_xH_y� even though it is a mixture of several hydro carbons.

3. Gaseous fuels: Natural gas (mainly Methane), coal gas (a mixture of methane and Hydrogen) etc.

Fuels	**Primary (natural)**	**Secondary (artificial)**
Solid fuels	wood, coal, peat, dung, etc.	coke, charcoal
Liquid fuels	petroleum	diesel, gasoline, kerosene, LPG, coal tar, naphtha, ethanol
Gaseous fuels	natural gas	hydrogen, propane, methane, coal gas, water gas, blast furnace gas, coke oven gas, CNG

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Solid fuel

Coal is a solid fuel

Solid fuel refers to various types of solid material that are used as fuel to produce energy and provide heating, usually released through combustion. Solid fuels include wood, charcoal, peat, coal, hexamine fuel tablets, and pellets made from wood (see wood pellets), corn, wheat, rye and other grains. Solid-fuel rocket technology also uses solid fuel (see solid propellants). Solid fuels have been used by humanity for many years to create fire. Coal was the fuel source which enabled the industrial revolution, from firing furnaces, to running steam engines. Wood was also extensively used to run steam locomotives. Both peat and coal are still used in electricity generation today. The use of some solid fuels (e.g. coal) is restricted or prohibited in some urban areas, due to unsafe levels of toxic emissions. The use of other solid fuels as wood is decreasing as heating technology and the availability of good quality fuel improves. In some areas, smokeless coal is often the only solid fuel used. In Ireland, peat briquettes are used as smokeless fuel. They are also used to start a coal fire.

Liquid fuels

A gasoline station

Liquid fuels are combustible or energy-generating molecules that can be harnessed to create mechanical energy, usually producing kinetic energy. They must also take the shape of their container; the fumes of liquid fuels are flammable, not the fluids.

Most liquid fuels in widespread use are derived from the fossilized remains of dead plants and animals by exposure to heat and pressure inside the Earth's crust. However, there are several types, such as hydrogen fuel (for automotive uses), ethanol, jet fuel and bio-diesel, which are all categorized as liquid fuels. Emulsified fuels of oil in water, such as orimulsion, have been developed as a way to make heavy oil fractions usable as liquid fuels. Many liquid fuels play a primary role in transportation and the economy.

Some common properties of liquid fuels are that they are easy to transport and can be handled easily. They are also relatively easy to use for all engineering applications and in home use. Fuels like kerosene are rationed in some countries, for example in government-subsidized shops in India for home use.

Conventional diesel is similar to gasoline in that it is a mixture of aliphatic hydrocarbons extracted from petroleum. Kerosene is used in kerosene lamps and as a fuel for cooking, heating, and small engines. Natural gas, composed chiefly of methane, can only exist as a liquid at very low temperatures (regardless of pressure), which limits its direct use as a liquid fuel in most applications. LP gas is a mixture of propane and butane, both of which are easily compressible gases under standard atmospheric conditions. It offers many of the advantages of compressed natural gas (CNG) but is denser than air, does not burn as cleanly, and is much more easily compressed. Commonly used for cooking and space heating, LP gas and compressed propane are seeing increased use in motorized vehicles. Propane is the third most commonly used motor fuel globally.

Fuel gas

A 20-pound (9.1 kg) propane cylinder

Fuel gas is any one of a number of fuels that are gaseous under ordinary conditions. Many fuel gases are composed of hydrocarbons (such as methane or propane), hydrogen, carbon monoxide, or mixtures thereof. Such gases are sources of potential heat energy or light energy that can be readily transmitted and distributed through pipes from the point of origin directly to the place of consumption. Fuel gas is contrasted with liquid fuels and from solid fuels, though some fuel gases are liquefied for storage or transport. While their gaseous nature can be advantageous, avoiding the difficulty of transporting solid fuel and the dangers of spillage inherent in liquid fuels, it can also be dangerous. It is possible for a fuel gas to be undetected and collect in certain areas, leading to the risk of a gas explosion. For this reason, odorizers are added to most fuel gases so that they may be detected by a distinct smell. The most common type of fuel gas in current use is natural gas.

Biofuels

Biofuel can be broadly defined as solid, liquid, or gas fuel consisting of, or derived from biomass. Biomass can also be used directly for heating or power—known as *biomass fuel*. Biofuel can be produced from any carbon source that can be replenished rapidly e.g. plants. Many different plants and plant-derived materials are used for biofuel manufacture.

Perhaps the earliest fuel employed by humans is wood. Evidence shows controlled fire was used up to 1.5 million years ago at Swartkrans, South Africa. It is unknown which hominid species first used fire, as both *Australopithecus* and an early species of *Homo* were present at the sites.[11] As a fuel, wood has remained in use up until the present day, although it has been superseded for many purposes by other sources. Wood has an energy density of 10–20 MJ/kg.[12]

Recently biofuels have been developed for use in automotive transport (for example bioethanol and biodiesel), but there is widespread public debate about how carbon efficient these fuels are.

Fossil fuels

Extraction of petroleum

Fossil fuels are hydrocarbons, primarily coal and petroleum (liquid petroleum or natural gas), formed from the fossilized remains of ancient plants and animals[13] by exposure to high heat and pressure in the absence of oxygen in the Earth's crust over hundreds of millions of years.[14] Commonly, the term fossil fuel also includes hydrocarbon-containing natural resources that are not derived entirely from biological sources, such as tar sands. These latter sources are properly known as *mineral fuels*.

Fossil fuels contain high percentages of carbon and include coal, petroleum, and natural gas.[15] They range from volatile materials with low carbon:hydrogen ratios like methane, to liquid petroleum to nonvolatile materials composed of almost pure carbon, like anthracite coal. Methane can be found in hydrocarbon fields, alone, associated with oil, or in the form of methane clathrates. Fossil fuels formed from the fossilized remains of dead plants[13] by exposure to heat and pressure in the Earth's crust over millions of years.[16] This biogenic theory was first introduced by German scholar Georg Agricola in 1556 and later by Mikhail Lomonosov in the 18th century.

It was estimated by the Energy Information Administration that in 2007 primary sources of energy consisted of petroleum 36.0%, coal 27.4%, natural gas 23.0%, amounting to an 86.4% share for fossil fuels in primary energy consumption in the world.[17] Non-fossil sources in 2006 included hydroelectric 6.3%, nuclear 8.5%, and others (geothermal, solar, tidal, wind, wood, waste) amounting to 0.9%.[18] World energy consumption was growing about 2.3% per year.

Fossil fuels are non-renewable resources because they take millions of years to form, and reserves are being depleted much faster than new ones are being made. So we must conserve these fuels and use them judiciously. The production and use of fossil fuels raise environmental concerns. A global movement toward the generation of renewable energy is therefore under way to help meet increased energy needs. The burning of fossil fuels produces around 21.3 billion tonnes (21.3 gigatonnes) of carbon dioxide (CO_2) per year, but it is estimated that natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide per year (one tonne of atmospheric carbon is equivalent to 44/12 or 3.7 tonnes of carbon dioxide).[19] Carbon dioxide is one of the greenhouse gases that enhances radiative forcing and contributes to global warming, causing the average surface temperature of the Earth to rise in response, which the vast majority of climate scientists agree will cause major adverse effects. Fuels are a source of energy.

Energy

The amount of energy from different types of fuel depends on the stoichiometric ratio, the chemically correct air and fuel ratio to ensure complete combustion of fuel, and its specific energy, the energy per unit mass.

Energy capacities of common types of fuel

Fuel	Specific energy (MJ/kg)	AFR stoich.	FAR stoich.	Energy @ $\lambda=1$ (MJ/kg$_{(Air)}$)
Diesel	48	14.5 : 1	0.069 : 1	3.310
Ethanol	26.4	9 : 1	0.111 : 1	2.933
Gasoline	46.4	14.7 : 1	0.068 : 1	3.156
Hydrogen	142	34.3 : 1	0.029 : 1	4.140
Kerosene	46	15.6 : 1	0.064 : 1	2.949
LPG	46.4	17.2 : 1	0.058 : 1	2.698
Methanol	19.7	6.47 : 1	0.155 : 1	3.045
Methane	55.5	17.2 : 1	0.058 : 1	3.219
Nitromethane	11.63	1.7 : 1	0.588 : 1	6.841

1 MJ ≈ 0.28 kWh ≈ 0.37 HPh.

Nuclear

Two CANDU ("CANada Deuterium Uranium") fuel bundles, each about 50 cm long and 10 cm in diameter

Nuclear fuel is any material that is consumed to derive nuclear energy. Technically speaking, all matter can be a nuclear fuel because any element under the right conditions will release nuclear energy,[*dubious – discuss*] but the materials commonly referred to as nuclear fuels are those that will produce energy without being placed under extreme duress. Nuclear fuel is a material that can be 'burned' by nuclear fission or fusion to derive nuclear energy. *Nuclear fuel* can refer to the fuel itself, or to physical objects (for example bundles composed of **fuel rods**) composed of the fuel material, mixed with structural, neutron moderating, or neutron reflecting materials.

Most nuclear fuels contain heavy fissile elements that are capable of nuclear fission. When these fuels are struck by neutrons, they are in turn capable of emitting neutrons when they break apart. This makes possible a self-sustaining chain reaction that releases energy with a controlled rate in a nuclear reactor or with a very rapid uncontrolled rate in a nuclear weapon.

The most common fissile nuclear fuels are uranium-235 (^{235}U) and plutonium-239 (^{239}Pu). The actions of mining, refining, purifying, using, and ultimately disposing of nuclear fuel together make up the nuclear fuel cycle. Not all types of nuclear fuels create power from nuclear fission. Plutonium-238 and some other elements are used to produce small amounts of nuclear power by radioactive decay in radioisotope thermoelectric generators and other types of atomic batteries. Also, light nuclides such as tritium (^{3}H) can be used as fuel for nuclear fusion. Nuclear fuel has the highest energy density of all practical fuel sources.

Fission

Nuclear fuel pellets are used to release nuclear energy.

The most common type of nuclear fuel used by humans is heavy fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear fission reactor; *nuclear fuel* can refer to the material or to physical objects (for example fuel bundles composed of fuel rods) composed of the fuel material, perhaps mixed with structural, neutron moderating, or neutron reflecting materials.

Fusion

Fuels that produce energy by the process of nuclear fusion are currently not utilized by humans but are the main source of fuel for stars. Fusion fuels tend to be light elements such as hydrogen which will combine easily. Energy is required to start fusion by raising temperature so high all materials would turn into plasma, and allow nuclei to collide and stick together with each other before repelling due to electric charge. This process is called fusion and it can give out energy.

In stars that undergo nuclear fusion, fuel consists of atomic nuclei that can release energy by the absorption of a proton or neutron. In most stars the fuel is provided by hydrogen, which can combine to form helium through the proton-proton chain reaction or by the CNO cycle. When the hydrogen fuel is exhausted, nuclear fusion can continue with progressively heavier elements, although the net energy released is lower because of the smaller difference in nuclear binding energy. Once iron-56 or nickel-56 nuclei are produced, no further energy can be obtained by nuclear fusion as these have the highest nuclear binding energies.[20] The elements then on use up energy instead of giving off energy when fused. Therefore, fusion stops and the star dies. In attempts by humans, fusion is only carried out with hydrogen (isotope of 2 and 3) to form helium-4 as this reaction gives out the most net energy. Electric confinement (ITER), inertial confinement (heating by laser) and heating by strong electric currents are the popular methods.

REFERANCE:-

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- P.K.NAG
- INTERNET