THERMAL ENGINNERING-1(TH-4)

CHAPTER 1:

CONCEPTS AND TERMINOLOGY

- **Thermodynamics**

  It is defined as the science of heat energy transfer and its effect on physical property of the substance.

  OR

  It may be defined as the science which deals with the conversion of heat into mechanical work or energy by using a suitable medium.

- **Thermodynamic System**

  Surrounding: Anything external to the system constitute as surrounding.

  System: A system is defined as any quantity of matter or a region in space having certain volume upon which our attention is concerned in analysis of problem.

  Surrounding: Anything external to the system constitute as surrounding.

  Boundary: System is separated from the surrounding by system boundary. This boundary may be fixed or movable.

  surrounding
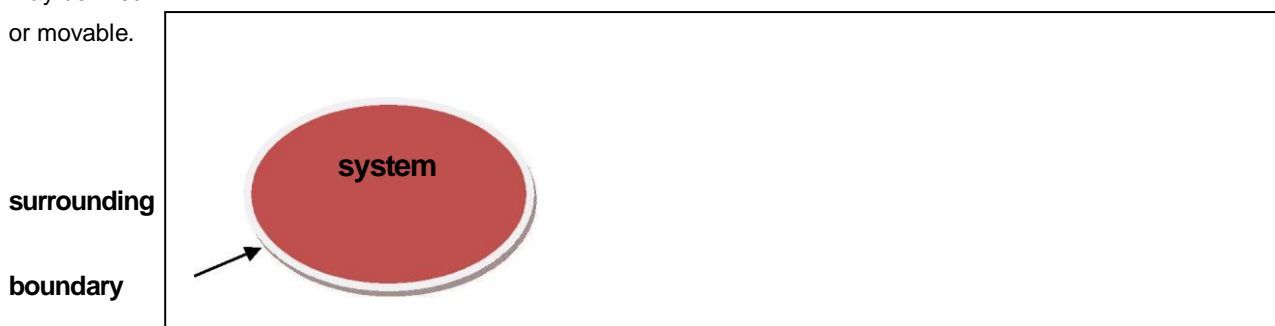
  boundary

  system

  system are classified into three types :-

- Open system
- Closed system
- Isolated system

  Open System
  It is also known as *flow system.* Open system is one in which both mass and energy crosses the boundary. Open system is also called control volume. Ex- reciprocating air compressor, turbine, pump etc.

  Closed System
  It is also known as *non-flow system*. In this system the mass within the boundary remains constant only energy interaction takes place with respect to the surrounding. Ex – Cylinder piston arrangement, Tea kettle.

  Isolated System
  An isolated system is one in which there is no interaction between the system and surrounding. There is no mass and energy transfer across the system. Ex- Universe,

MACROSCOPIC AND MICROSCOPIC APPROACH

Study of thermodynamics is done by two different approaches.

- **Macroscopic approach**: The term macroscopic is used in regard to larger units which is visible to the naked eye. In macroscopic approach certain quantity of matter is considered without taking into consideration the events occurring at molecular level. In other words macroscopic approach is concerned with overall behaviour of matter. This type of study is also known as *classical thermodynamics*.
- **Microscopic approach**: In microscopic approach matter is considered to be composed of tiny particles called molecules and study of each particle having a certain position, velocity and energy at a given instant is considered such a study is also called as *Statistical thermodynamics.*

CONCEPT OF CONTINUUM

The system is regarded as a continuum i.e. the system is assumed to contain continuous distribution of matter. Thus, from the continuum point of view, the matter is seen as being distributed through space and treats the substance as being continuous disregarding the action of individual molecules. There are no voids and values of action of many molecules and atoms.

THERMODYNAMIC PROPERTY

- **PROPERTY-**A thermodynamic property refers to the characteristics by which the physical condition or state of a system can be described such as pressure, volume, temperature etc. & such characteristics are called properties of a system.
- **PRESSURE-**Pressure is defined as force per unit area.

  Units of pressure are as follows In S.I Pascal (Pa) and 1 Pa= $1N/m^2$

  1 Bar= $10^5 N/m^2$ = 100 KPa

  1 ATM=760mm of Hg or 1.013 bar or 101.325KPa

- **TEMPERATURE-**The temperature is a thermal state of a body which determines the hotness or coldness of a body. The temperature of a body is proportional to the stored molecular energy i.e. the average molecular kinetic energy of the molecules in a system.
  Units of temperature are degree Celsius or Kelvin.

Intensive and Extensive Property:

- Intensive property: The properties which are independent of mass of the system are known as intensive properties. Its value remains the same whether one considers the whole system or only a part of it. The intensive property includes pressure, temperature, specific volume, specific energy, specific density etc.

- Extensive property: the property which depends upon mass of the system are known as extensive property. The extensive properties include volume, energy, enthalpy, entropy etc.

State: The condition of physical existence of a system at any instant of time is called state.

Thermodynamic Processes:

When any property of a system changes, there is a change in state and the system is then said to have undergo a thermodynamic process.

The commonly used processes are:

1. Isochoric Process – The process which takes place at constant volume is said to be isochoric process.
2. Isobaric Process – The process which takes place at constant pressure is said to undergo an isobaric process.
3. Isothermal Process- The process which takes place at constant temperature is said to undergo an isothermal process.
4. Adiabatic Process- The process where there is no heat transfer between the system and the surrounding. The reversible adiabatic process is known as isentropic process.

   The other processes are polytrophic process, throttling process, free expansion process and hyperbolic process.

Thermodynamic Cycle:

When a process is performed in such a way that the final state is identical with the initial state, it is then known as a thermodynamic cycle or cyclic process.
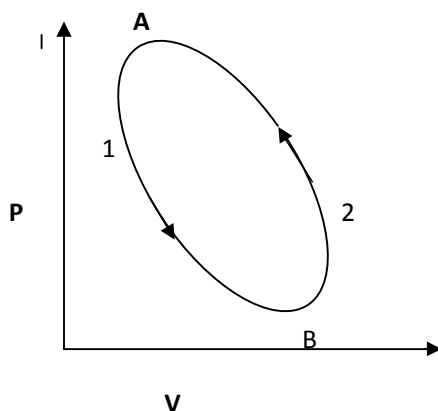
In the fig above:

A-1-B and **A-2-B** represents *process*

Whereas **A-1-B-2-A** represent a *thermodynamic cycle*.

THERMODYNAMIC EQULIBRIUM:

A system is said to be in thermodynamic equilibrium when no change in any macroscopic property is registered, if the system is isolated from its surrounding.

Thermodynamics mainly studies the properties of physical system that are found in equilibrium state.

A system will be said to be in thermodynamic equilibrium if the following three conditions of equilibrium is satisfied.

a) Mechanical Equilibrium
b) Chemical Equilibrium
c) Thermal Equilibrium

Mechanical Equilibrium- when there is no unbalanced force on any part of the system or in-between the system and surrounding then the system is said to be in mechanical equilibrium. For example if the pressure is not uniform throughout the system, then internal changes in the state of the system will take place until the mechanical equilibrium is reached.

Chemical Equilibrium- when there is no chemical reaction or transfer of matter from one part of the system to another such as diffusion or solution, then the system is said to exists in a state of chemical equilibrium.

Thermal Equilibrium- when there is no temperature difference between the parts of the system or between the system and the surrounding, it is then said to be in thermal equilibrium.
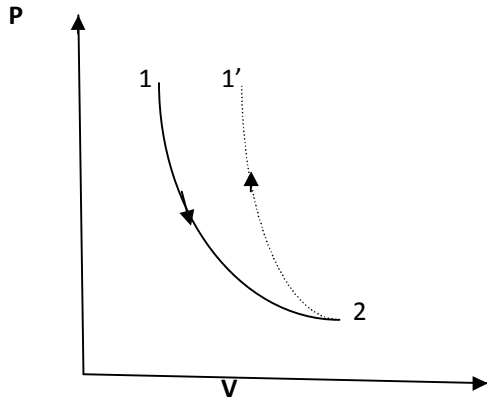
REVERSIBLE PROCESS:

A process which can be reversed in direction and the system retraces the same continuous series of equilibrium states it is said to be reversible process. A reversible process should be carried out with absolute slowness, so that the system will be always in equilibrium. In actual practise a reversible process cannot be attained, but it can be approximated as a closely as a possible. For example a gas confined in a cylinder with a well lubricated piston can be made to undergo a reversible process by pushing or pulling the piston in slow motion.
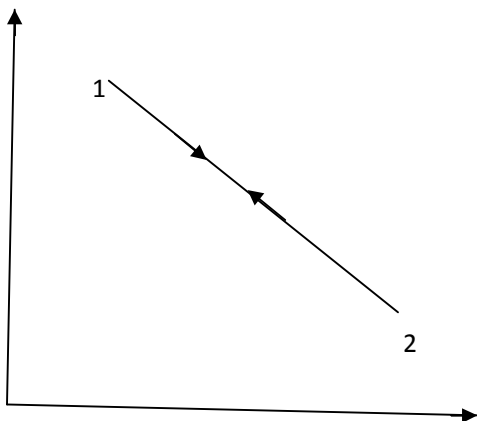
IRREEVERSIBLE PROCESS

A process in which the system passes through a sequences non-equilibrium state i.e. The property such as pressure, volume, temperature is not uniform throughout the system it is known as an irreversible process. This process will not retrace the reverse path to restore the original state. The heat transfer by convection, combustion of air and fuel etc are few examples of irreversible process.

QUASI-STATIC PROCESS

The word quasi means *almost.* This process is a succession of equilibrium states and infinite slowness is the characteristic feature of quasi-static process. A quasi-static process is also called as reversible process, the basic difference is that in a quasi static process not all the point but almost major points is in equilibrium condition.
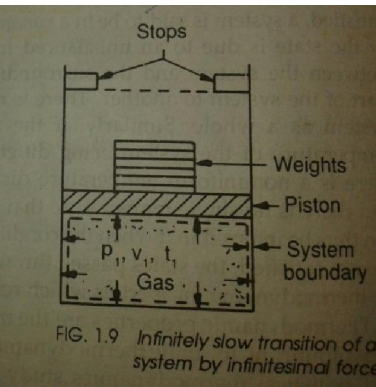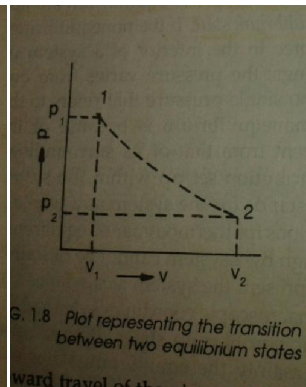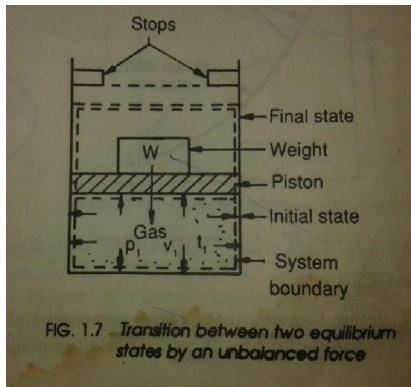

FIG. 1.7 Transition between two equilibrium states by an unbalanced force

G. 1.8 Plot representing the transition between two equilibrium states

FIG. 1.9 Infinitely slow transition of a system by infinitesimal force

Fig 1   **Fig 2**

Let us consider a system of gas contained in a cylinder as shown in fig 1 . The system is initially an equilibrium state. The weight W on the piston just balances the upward force exerted by the gas. If the weight is removed there will be an unbalanced force between the system and the surrounding, and the piston will move upward till it hits the stops .the system will be again in a equilibrium state but if the same process as shown if fig 2 is done by slowing removing very small pieces of weight one by one then the piston will move upward slowly thus the system will be in equilibrium.

CHAPTER 2:

ENERGY AND WORK TRANSFER

A closed system interacts with the surrounding by energy transfer and this energy transfer takes place in two ways i.e. *Work transfer* and *Heat transfer.*

Heat and work are the main mode of energy transfer and there are certain similarities and differences between heat and work.

- The heat and work are boundary phenomena. They are observed at the boundary of the system.
- When a system undergoes a change in state, heat transfer or work done may occur.
- Heat and work are path function and depends upon the process. Hence they are not thermodynamic property and are inexact differential.
- Work is said to be *high grade energy* and heat low *grade energy*. The complete conversion of low grade energy into high grade energy is impossible.

Work Transfer

The action of a force on a moving body is identified as work. For the work transfer the system has to be such selected that its boundary just move. There cannot be work transfer in a closed system, without moving the system boundaries. In a cylinder piston arrangement the top of the system is moving system boundary and the work is transferred by the movement of the piston.
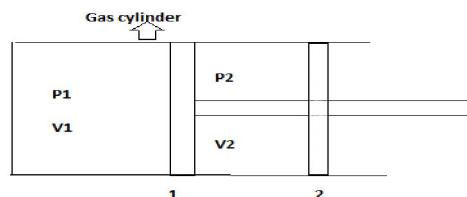
Work done by the system is considered to be *positive* and work done on the system is taken as *negative.*

Work done= force X displacement

Unit of work: Newton-meter (N-m) or Joule(J)

The rate at which work is done upon or by the system is known as *power.* The unit of power is J/s or watt.

PdV work or Displacement Work

Let us consider a gas in the cylinder as shown in the fig above. Let the system initially be at pressure P1 and volume V1. The system is in thermodynamic equilibrium , the piston is the system boundary which moves due to gas pressure. Let the piston move out to a new final position 2 which is also in thermodynamic equilibrium specified by pressure P2 and volume V2. When the piston moves an infinitesimal distance **dl** if **a** be the area of the piston.

The force F acting on the piston will be
F= p X a
The amount of work done by the gas on the piston will be
dW = F. dl = p X a X dl = pdV
where dV= a X dl
when the piston moves out from position 1 to position 2 then the amount of work done b the system will be
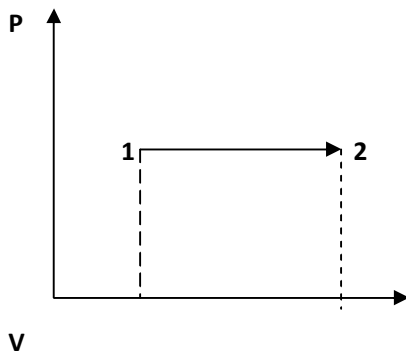$W_{1-2} = \int_{v1}^{v2} pdv$
The above equation represents the displacement work.

Displacement work applied to different thermodynamic process
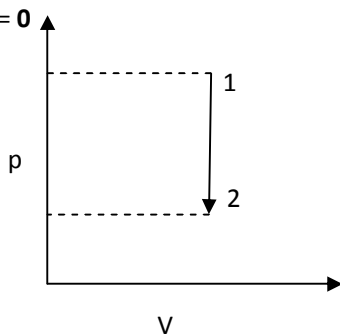
1. **Isobaric process**

$W_{1-2} = \int_{v1}^{v2} pdv$

$= p(v_2 - v_1)$

2. **Isochoric process**

$W_{1-2} = \int_{v1}^{v2} pdv$

= 0

3. Isothermal process

In this process pv= constant

$$pV = P_1V_1 = C$$

$$P = P_1V_1/V$$

$$W_{1-2} = \int_{v1}^{v2} pdv$$

$$W_{1-2} = p_1V_1\int_{v1}^{v2} dV/V$$

$$= p_1V_1 \ln p_1/p_2$$

4. Polytrophic process

The process in which expansion and contraction takes lace according to the law $pV^n = C$

$$pV^n = p_1v_1^n = p_2V_2^n = C$$

$$W_{1-2} = \int_{v1}^{v2} pdv$$

$$= \int_{v1}^{v2} (p_1V_1^n/ V^n). dV$$

$$= p_1V_1^n[V^{-n+1}/ -n+1]_{v1}^{v2}$$

$$= [p_2V_2^n *V_2^{1-n} - p_1V_1^n *V_1^{1-n}]/ (1-n)$$

$$= (p_1V_1 - p_2V_2) / (n-1)$$

HEAT TRANSFER

Heat is defined as the form of energy that is transferred across a boundary by virtue of temperature difference between the system and the surroundings.

It the heat flows into the system or the system receives heat then heat transfer Q is taken as *positive* and if heat is rejected from the system then Q is taken as *negative.*

The heat transfer takes place by three different modes

1. Conduction: the transfer of heat between two bodies in direct contact is called conduction. It is a process of heat transfer from one particle of a body to another in the direction of fall of temperature. For example heat transfer through solids is by conduction.
2. Convection : The process of heat transfer from one particle to another by convection currents i.e. transfer of heat between the wall and fluid system in motion. In this case, the particles of the body move relative to each other.
3. Radiation : Heat transfer between two bodies separated by empty space or gases through electromagnetic waves is radiation.

Sensible heat: The heat required for change from liquid state to vapourisation/boiling point is called sensible heat. It is the amount of heat absorbed by one kg of water, when heated at a constant pressure, from the freezing point (0^0C) to the temperature of formation of steam.

Latent heat: It is the amount of heat absorbed to evaporate one kg of water at its boiling point without change of temperature.

Specific Heat : The amount of heat required to raise the temperature of unit mass of a substance through one degree is known as specific heat.

The unit of specific heat is KJ/kg K

Mathematically heat required to raise the temperature of a body is

Q = m C(T_2-T_1) in kJ

Where, m= mass of the substance in kg

> C= specific heat in KJ/Kg K
> T_1= initial temperature in degree Celsius or Kelvin
> T_2= final temperature in degree Celsius or Kelvin

Specific heat at constant volume (Cv) : It is defined as amount of heat required to raise the temperature of a unit mass of a gas by one degree at constant volume.

Specific heat at constant pressure (Cp) : It is defined as amount of heat required to raise the temperature of a unit mass of a gas by one degree at constant pressure

ENERGY:

The energy is defined as the capacity to do work. In broad sense energy is classified as *stored energy* and *transient energy.*

The energy that remains within the system boundary is called ***stored energy*** e.g. potential energy, kinetic energy and internal energy.

The energy which crosses the system boundary is known as energy in transition e.g. heat, work, electricity etc.

DIFFERENT FORM OF STORED ENERGY

1. POTENTIAL ENERGY-The energy posed by a body by a virtue of its position or state of rest is known as potential energy
   P.E=W X h=mgh
   W=weight of the body in N
   M=mass of the body in kg
   g=acceleration due to gravity
   h=height in meter

2. KINETIC ENERGY-The energy posed by a body by virtue of its motion.

Mathematically kinetic energy,

K.E=1/2 mv^2

V=velocity of the body

3. INTERNAL ENERGY –The energy posed by a body or a system by virtue of its intermolecular arrangement and motions of molecules. The change in temperature causes the change in internal energy. It is usually denoted by U.

The sum of the above three energies is the total energy of the system

E=P.E+ K.E+ U

But when the system is stationary and the effect of gravity is neglected then P.E=0 and K.E=0. Thus

E = U

I.E the total energy is equal to the total energy of system.

CHAPTER 3.0

THERMAL ENGINEERING

FIRST LAW OF THERMODYNAMIC

Introduction

Heat and work are different forms of the same entity called energy. Energy is always conserved. Energy may enter a system as heat and leave as work and vice-versa.

Energy has two forms-transit energy and stored energy.

The internal energy is the stored energy. Whenever heat and work enters a system, stored energy increases and when heat & work leaves the system stored energy decreases.
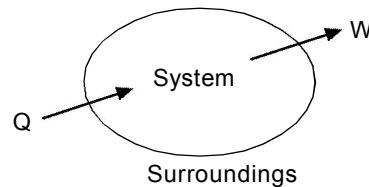
3.1 First law of thermodynamics

Whenever heat is absorbed by a system it goes to increases its internal energy plus to do some external work (Pdv work) i.e.

$$Q = \Delta E + W$$

Where Q is the energy entering a system, ΔE increase in internal energy, W – producing some external work.
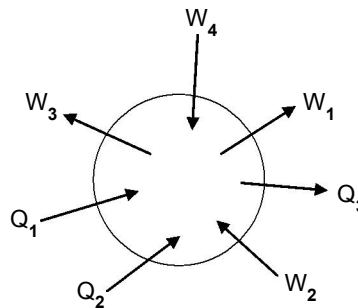
$$\delta Q = dE + Pdv$$

Sometimes more than two energy transfers, so it becomes.

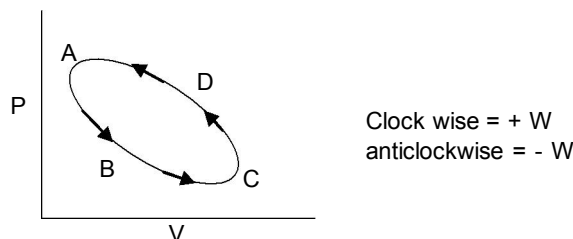$$Q_1 + Q_2 - Q_3 = \Delta E + W_1 - W_2 + W_3 - W_4$$

Sign convention

It will be '+Q' if heat goes into the system and '-Q' if heat goes out of the system +W when it is done by the system and –w is done on the system.
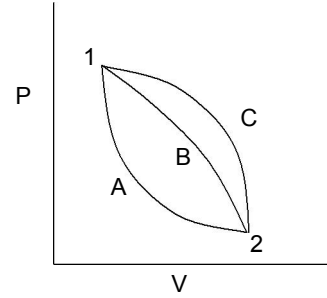

Cyclic process

For a cyclic process, the work done is the area enclosed by the PV curve.

Clock wise = + W
anticlockwise = - W

[11]

3.2 Energy as a system property

Let a system changes from state 1 to state 2 via path A path B and Path C, which as follows

Applying first law of thermodynamics to path A.

$$Q_A = \Delta E_A + W_A$$

For path B $Q_B = \Delta E_B + W_B$

If process A & B form a complete cycle

$$\sum Q = \sum W$$

$$(Q_A + Q_B) = \Delta E_A + E_B + (W_A + W_B)$$

$$\sum Q = \Delta E_A + E_B + \sum W$$

$$\Rightarrow \Delta E_A = -\Delta E_B$$

Similarly $\Delta E_A = -\Delta E_B$

$$\Rightarrow \Delta E_B = \Delta E_C$$

So it is independent of path hence a property extensive or in nature.

Different forms of stored energy

Energy can be store in a system by two modes.
(i)   Macroscopic mode
(ii)   Microscopic mode

(i) Macroscopic mode

In this mode, the mode of stored energy stored in two forms,

$$E_{KE} = \left(\frac{1}{2}\right) MV^2$$

$$E_{PE} = mgz$$

(ii) Microscopic mode

This mode of stored energy refers to energy stored in molecular and atomic structure. Hence it is called molecular internal energy on simply internal energy. Then including

1.   Translational KE
2.   Rotational KE
3.   Vibration energy
4.   Electronic energy
5.   Chemical energy
6.   Nuclear energy

$$L = L_{translation} + L_{rotational} + L_{vibrtion} + L_{electronic} + L_{chemical} + L_{nuclear}$$

Total energy

$$E = E_{KE} + E_{PE} + U$$

[12]

In absence of motion, gravity E_{KE} , E_{PE} = 0

$$SoE = U$$
$$Q = \Delta U + \int Pdv$$

3.3 First law for a closed system undergoing a cyclic process.

3.5 Enthalpy concept

Enthalpy is a state property of a system. It is denoted by

H = U + Pv

It is a point function and an intensive property.

Specific enthalpy is given by

$$h = u + \frac{1}{m}PV = u + Pv$$

3.6 First law for a steady flow process

Steady flow process

A flow process is the one in which a fluid enters the system and then leaves if after a work interaction.

The mass flow rate and energy flow rate across the system boundary are constant.

Important terms

Flow work – whenever a certain amount of mass enters a system, an amount of work is required to push the mass into the system and out of it to maintain the continuity of flow.

i.e. Flow work = PV

Control Volume

For computation of mass and energy notes during a flow process, it is convenient to focus attention upon a certain fixed region in space called control volume.

Control surface

The boundary line defining the control volume is called control surface.

Stored energy of a system in a flow process

During a steady state flow, there is neither any accumulation of mass nor energy.

$$(Mass\,flow\,rate)_{in} = (Mass\,flow\,rate)_{out}$$
$$\Sigma Energy_{in} = Energy_{out}$$

Now, the total energy of a fluid at any section of the control volume.

$$E = U + \frac{1}{2}(MV^2) + mgz$$
$$e = u + \frac{1}{2}V^2 + gz$$

STEADY FLOW ENERGY EQUATION

As all energy is conserved

$$\sum Energy_{in} + Heat\, flux = \sum Energy_{in} + Work_{output}$$

i.e.

$$U_1 + \frac{1}{2}mV_1^2 + mgz_1 + P_1V_1 + Q$$

$$= U_2 + \frac{1}{2}mV_2^2 + mgz_2 + P_2V_2 + W$$

$$\left[h_1 + \frac{1}{2}mV_1^2 + mgz_1 + Q \right] + \left[h_2 + \frac{1}{2}mV_2^2 + mgz_2 + W \right]$$

On the basis of per unit mass flow rate

$$h_1 + \frac{V_1^2}{2} + gz_1 + \frac{Q}{m}$$

$$h_2 + \frac{V_2^2}{2} + gz_2 + \frac{W}{m}$$

$$\boxed{or\ \ h_1 + \frac{V_1^2}{2} + gz_1 + Q = h_2 + \frac{V_2^2}{2} + gz_2 + W}$$
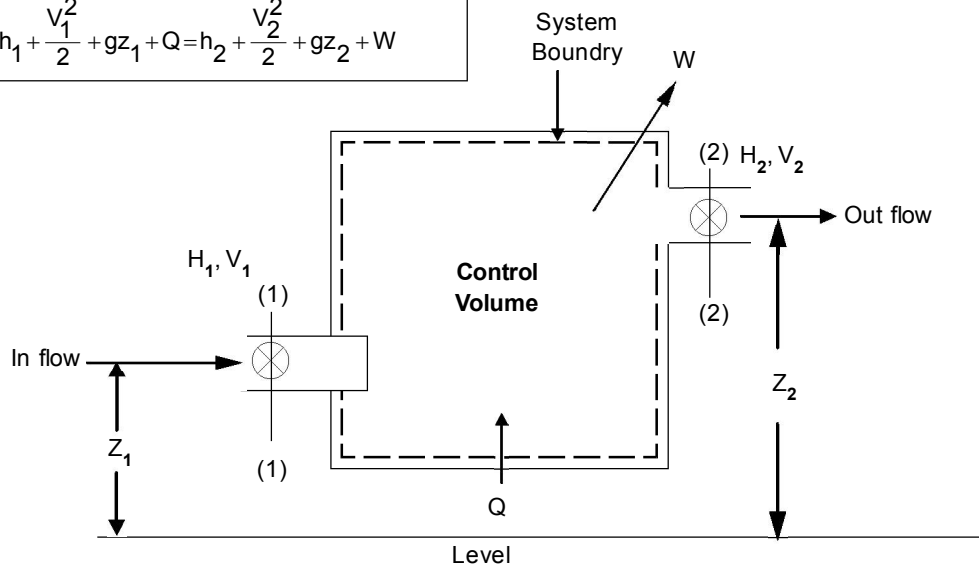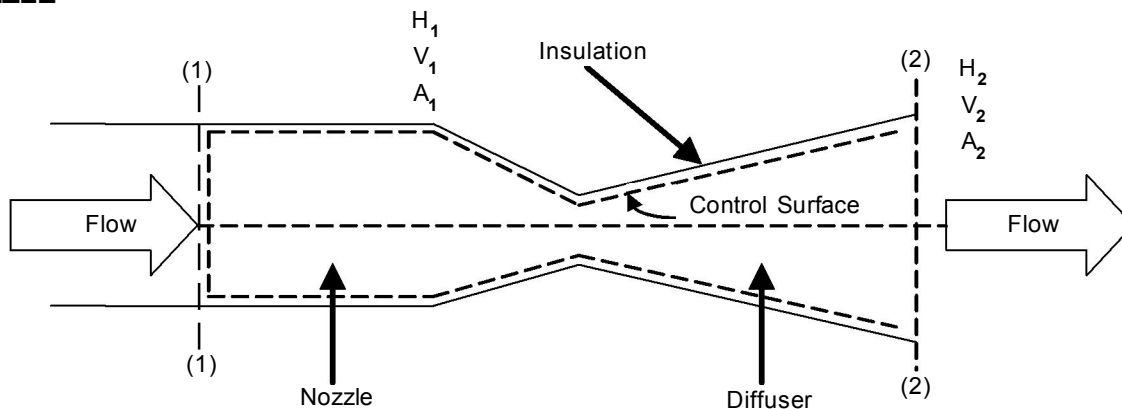

Fig- Steady flow

NOZZLE

**Fig- A Steady flow process through a nozzle.**

A nozzle is a device used to throttle a fluid whereupon its pressure energy is converted into kinetic energy. The enthalpy of fluid decreases as the velocity of the fluid increases because of a higher fluid velocity at the nozzle outlet, a nozzle is harnessed to gain a high thrust in rockets and jet engines and drive impulse type steam and gas turbines.

[14]

Compressor

A compressor compresses air or a gas by harnessing external work fed from a prime mover. The increase in the gas pressure is accompanied by the temperature rise. If the compressor is perfectly insulated and the compression is adiabatic then it requires the minor work input to increase the gas pressure. All the generated heat of compression is expanded to compresses the gas as no heat is allowed to escape.

So $Q = 0$

Mass flow route of the gas = M and $V_1 = V_2$
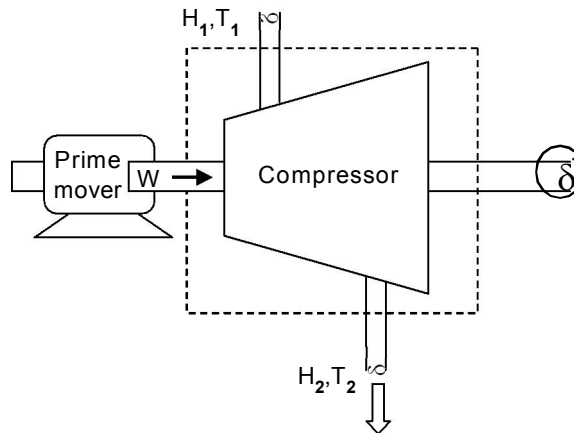
$Z_1 = Z_2$,

By applying SFEE

$h_1 = h_2 + (-W_C)$

(-) sign before Wc refers to the work done on the gas (system)

$W_C = M(h_2 - h_1)$

$= MC_P (T_2 - T_1)$

Example

An air compressor compresses air from $0.1 MP_a$ / 300K to $1 MP_a$. The compressor casing is well insulated, yet there is a heat loss to the surrounding to the extent of 5% of the compressor work.

Determine air temp at outlet and power input given

$V_1 = 40 m/s$, $V_2 = 100 m/s$, $A_1 = 100 cm^2$, $A_2 = 20 cm^2$, $C_P = 10^3 J Kg^{-1} K^{-1}$

Solution

$P_2 V_2 = RT_2$ or $T_2 = P_2 \, V_2/R$, V_2 - Specific volume.

We have $m_1 = m_2$

$$\frac{a_1 V_1}{v_1} = \frac{a_2 V_2}{v_2}$$

$$P_1 v_1 = RT_1$$

$$v_1 = \frac{RT_1}{P_1} = \frac{287 \times 300}{0.1 \times 10^6}$$

$$= 0.861 m^3 kg^{-1}$$

and $$v_2 = \frac{a_2 v_2}{a_1 v_1} \times V_1 = \left(\frac{20}{100}\right)\left(\frac{100}{40}\right) \times 0.861$$

$$= 0.4305 \, m^3 kg^{-1}$$

$$T_2 = P_2 v_2 / R$$

$$= \frac{1 \times 10^6 \times 0.4305}{287} = 1500K$$

[15]

$$Z_1 = Z_2$$

$$Q = 5\% \, W_C$$

$-Q$ as rejected

$-W \cap$ W.D on the system

$$H_1 + \frac{1}{2}MV_1^2 + (-Q)$$

$$= H_2 + \frac{1}{2}MV_2^2 + (W_C)$$

$$-0.5W_C + W_C$$

$$= M(h_2 - h_1) + m\left(v_2^2 - v_1^2\right)$$

$$0.95W_C = 0.4646 \times C_P\left[(T_2 - T_1) + \frac{1}{2}(V_2^2 - V_1^2)\right]$$

$$m = \frac{A_1V_1}{V_1}$$

$$= \left(100 \times 10^4 \, m^2\right) \times \frac{40m^5 - 1}{0.861} = 0.46457 kg5^{-1}$$

$$W_C$$

$$= 0.4646 \times \left[10^3(1500 - 300) + \frac{1}{2}\left(100^2 - 40^2\right)\right]$$

$$= 59889 / 7w$$

$$= 588.9kw \ (Ans)$$

Nozzle

There is no work output : W = O

No heat influx or escape Q = 0

For a horizontal disposition

$$Z_1 = Z_2$$
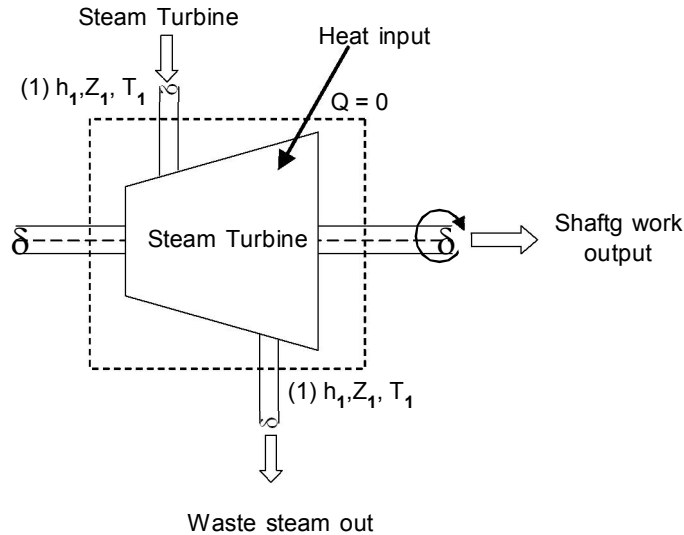
And so the SFEE applied to the nozzle boils down to

$$h1 + \frac{1}{2}\left(V_1\right)^2 = h2 + \frac{1}{2}(V_2)^2$$

If $V_2 \gg V_1$, then

$$V_2 = \sqrt{2(h_1 - h_2)}$$

$$= \sqrt{2C_P(T_1 - T_2)}$$

Turbine

Steam Turbine

Heat input

(1) h_1, Z_1, T_1

$Q = 0$

δ — — — Steam Turbine — — — δ → Shaftg work output

(1) h_1, Z_1, T_1

Waste steam out

A steam turbine receives a superheated, high pressure steam that experiences its. Enthalpy drop as the steam passes over the turbine blades. This enthalpy drop is converted into the kinetic energy of rotation of the blades mounted on the turbine drum. The turbine is well insulated which gives rise to the maximum work output. The turbine is well insulated.

$Q = 0$

Steam velocity at the turbine input = the steam velocity at the output

i.e. $V_1 = V_2$

The turbine is positioned horizontally

$Z_1 = Z_2$

Applying SFEE to the control volume
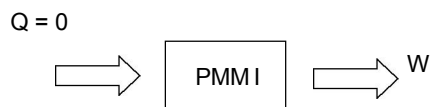
$H_1 = h_2 + W$

$W = h_1 - h_2$

$= C_P (T_1 - T_2)$

$W = MC_P (T_1 - T_2)$

3.7 perpetual motion machine

PMMI refers to the perpetual motion machine of the first kind. It is a hypothetical machine that will continuously churn out work but without absorbing heat from its surroundings.

$Q = 0$

→ PMM I → W

But such a machine is not feasible from a practical point of view, for it violates law of conservation of energy (first law of thermodynamics).

$W = 0$

→ PMM I (reverse) → Q
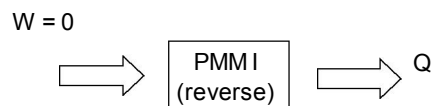
The reverse of perpetual machine is also not true. It s a hypothetical machine which is not feasible as if violates the first law of thermodynamics.

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Chapter 4.0

SECOND LAW OF THERMODYNAMICS

4.1 Limitation of first law

There are two basic limitations of the first law of thermodynamics

(1)   First law does not differentiate between heat and work.

It assumes complete inter-convertibility of the two. Though work being a high grade energy can be fully converted into heat but heat cannot be completely converted to work.

(2)   It does not permit us to know the direction of energy transfer. We cannot ascertain whether heat will flow from a higher temperature body to a lower temperature body vice versa.

4.2 Thermal Reservoir

A thermal reservoir is a heat source or heat sink that remains at a constant temperature, regardless of energy interaction.

Otherwise a thermal energy reservoir (TER) is a large system body of infinite heat capacity which is capable of absorbing or rejecting a finite amount of heat without any changes in its thermodynamic co-ordinates.

The high temperature reservoir (T_H) that supplies heat is a source.

Sink – Low temperature reservoir to which heat is rejected.

Example

Ocean water and atmospheric air are two good examples.
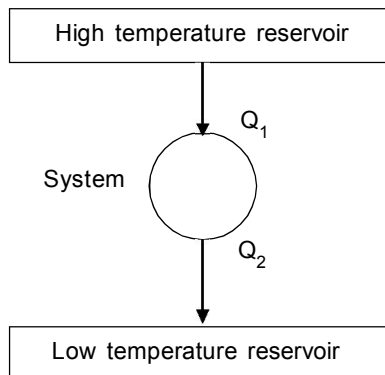
4.3 Concept of heat engine

A heat engine is a device that can operate continuously to produce work receiving heat from a high temperature T_H and rejecting non-converted heat to a low temperature sink.
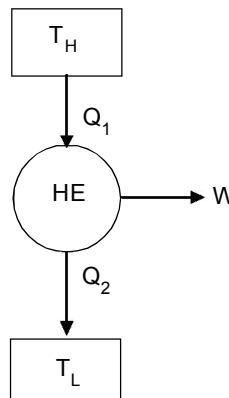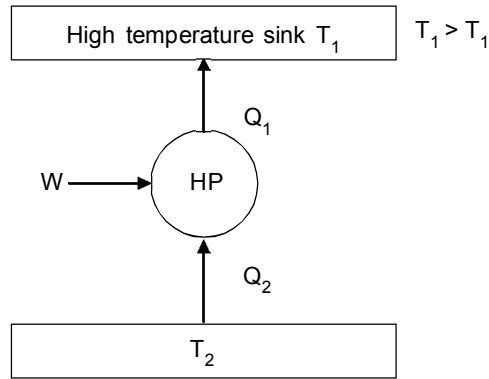

$$\text{Effect} = \frac{\text{output}}{\text{input}} = \frac{W}{Q_1}$$

But, $W = Q_1 - Q_2$ in a cycle

So $\eta_{\text{thermal}} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$

Heat Pump

A heat pump is a reversed heat engine. It receives heat from a low temperature reservoir (source) and rejects it to high temperature reservoir (since) for which an external work which is supplied to the pump.

The efficiency of a heat pump cycle is usually called the coefficient of performance. It is the desired effect upon the external work supplied for obtaining that desired effect.

$$COP = \frac{Desired\ effect}{Work\ input}$$

$$COP_{HP} -= \frac{Q_1}{W}$$

$$Again\ \sum_{cycle} Q = \sum_{cycle} W$$

$$\therefore Q_1 - Q_2 = W$$

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$

Refrigerator

A refrigerator is similar to a heat pump. It operates as a reversed heat engine. Its duty is to extract heat as much as possible from the cold body and deliver the same to high temperature body.

The desired effect of a refrigerator is to remove Q_2 heat infiltrating into the cold space. By using the external work it rejects Q_1 heat to the high temperature reservoir. Therefore,

$$COP_{ref} = \frac{Q_2}{W}$$

$$Again\ \sum_{cycle} Q = \sum_{cycle} W$$

$$\therefore Q_1 - Q_2 = W$$

$$COP_{ref} = \frac{Q_2}{Q_1 - Q_2}$$
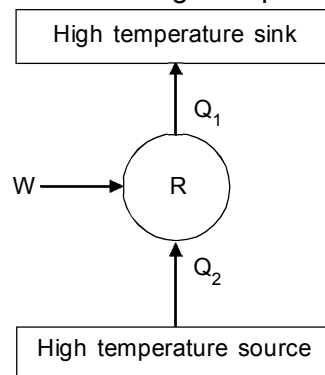
4.4 Statement of second law of the thermodynamics

Clausius statement

It is impossible to construct a device that will produce no effect other than the transfer of heat from a low temperature body to a high temperature body while operating in a cycle.

Kelvin Planck statement

No heat engine, operating in cycle, can convert entire heat into work. It is impossible to build a heat engine that can register 100% efficiency.

Note – T_C K-P statement is of relevance to a heat engine. The C-statement relates more directly to a reversed heat engine.

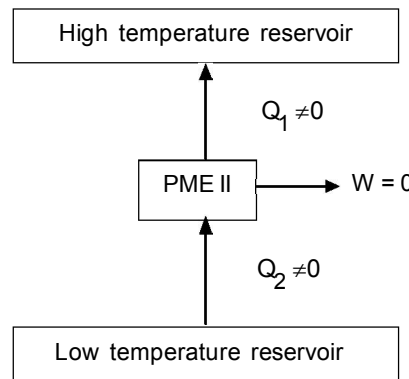**Perpetual motion machine II**

It is a hypothetical machine that will continuously pump out heat from a low temperature reservoir (T_2) and delivers the same to a high temperature reservoir at (T_1) without taking up any input work from surroundings.

```
        ┌─────────────────────────────────┐
        │   High temperature reservoir    │
        └─────────────────────────────────┘
                        ↑
                     Q₁ ≠ 0
               ┌──────────┐
               │  PME II  │──────→ W = 0
               └──────────┘
                        ↑
                     Q₂ ≠ 0
        ┌─────────────────────────────────┐
        │    Low temperature reservoir    │
        └─────────────────────────────────┘
```

4.5 Carnot cycle

The cannot cycle is a hypothetical cycle developed Nicholas Sadi Carnot (1796-7832) a French military engineer. It is meant for a heat engine or a reversed heat engine. All the process involved in this cycle are reversible, thereby ensuring the best possible device that once could construct. This cycle comprises 4 reversible processes.

Process 1-2 reversible isothermal heat addition

Heat (Q_{add}) flows from a high temperature reservoir to the working fluid which is at a constant temperature but only infinitesimally below that of the source.

$$Q_{add} = \Delta U + W_{1-2}, \ \Delta U = 0$$

$$Q_{add} = W_{1-2} \ (\text{as isothermal process})$$
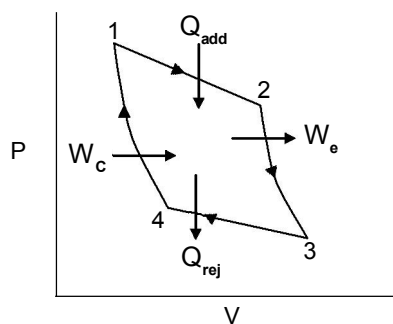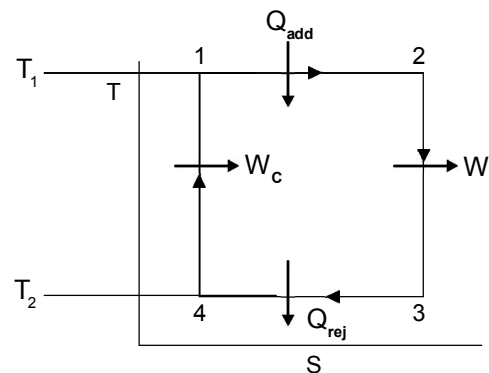
(a) PV diagram   (b) TS diagram

Process 2-3 (adiabatic expansion)

The working fluid expands through a turbine or expander adiabatically producing a net positive work output.

here $Q = 0$

$$\therefore O = \Delta U_{2-3} + W_{2-3}$$

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Process 3-4 (Isothermal heat rejected)

Heat (Qrej) is rejected by the fluid to the sink-both one at a constant temperature, but differ only by an infinitesimal amount.

$\Delta U = 0$, isothermal proces

$\therefore - Q_{rej} = - W_{3-4}$

– Q implies heat has been rejected by the system.

– W implies work has been done on the system.

Process 4-1 (Reversible adiabatic compression)

The temperature of the working fluid is raised back to the temperature level of high temperature through adiabatic compression, i.e. Q = 0

$O = \Delta U_{4-1} + - W_{4-1}$

$\therefore \Delta U_{4-1} = W_{4-1}$

As the two isothermal and two adiabatic complete the cycle.

So $\quad \sum\limits_{cycle} Q_{net} = \sum\limits_{cycle} W_{net}$

Or, $Q_{add} + (-Q_{rej}) = W_{1-2} + W_{2-3} - (W_{3-4} + W_{4-1})$

$\quad Q_{add} - Q_{rej} = W_e - W_c$

So, the efficiency

$\eta = \dfrac{\text{Net work output}}{\text{Net heat input}} = \dfrac{W_e - W_c}{Q_{add}}$

$\quad = \dfrac{Q_{add} - Q_{rej}}{Q_{add}} = 1 - \dfrac{Q_{rej}}{Q_{add}}$

Aliter

Refer to the TS diagram

Ne work done, W_{net} = area 1-2-3-4

$= \text{Side } 1-4 \ \text{x Side } 1-2$

$= T_1 - T_2 \ \text{x } S_2 - S_1$

$Q_{add} = T_1(S_2 - S_1)$

So efficiency, $\eta = \dfrac{W_{net}}{Q_{add}} = \dfrac{(T_1 - T_2)\Delta S}{T_1 \Delta S} = 1 - \dfrac{T_2}{T_1}$

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4.6. Application of second law is heat engine, heat pump, refrigerator and determination of cop and efficiencies.

Clausius statement

According to second law without work input heat cannot flow from low temperature to high temperature.

Case of heat engine
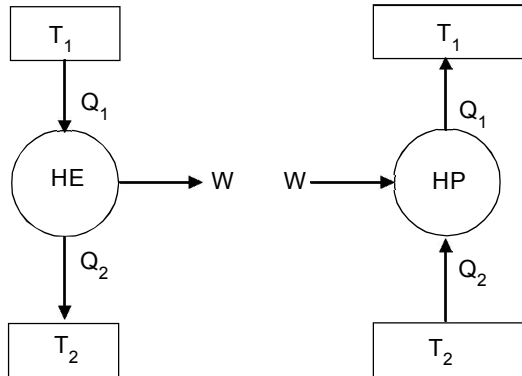
Kelvin plank statement

No heat engine operating in a cycle can convert entire heat into work.

in the above engine.

$Q_1 = Q_2 + W$

that means, Q_2 is rejected along with W output

$\Rightarrow Q_1 \neq W$

In a heat pump

$W + Q_2 = Q_1$

$W = 0, Q_2 = Q_1$

which is impossible, $\Rightarrow W \neq 0$

In a refrigerator
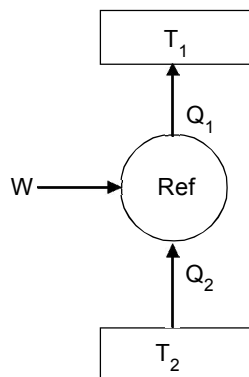
as like heat pump.

$$(COP)_{HP} = \frac{D.E}{Work_{input}} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

as $\dfrac{Q_1}{T_1} = \dfrac{Q_2}{T_2}$ (according to carnot's theory)

$$(COP)_{ref} = \frac{D.E}{Work_{ref}} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

$$1 + COP_{ref} = 1 + \frac{T_2}{T_1 - T_2} = \frac{T_1 - T_2 + T_2}{T_1 - T_2}$$

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

If installed backward, your household air conditioner will function as a heat pump cooling the surrounding but heating the room.

CHAPTER 6.0

IDEAL GASES & REAL GASES

6.1. Boyle's Law

The volume of a given mass of gas is inversely proportional to its absolutely pressure at constant temperature.

i.e. $V \alpha \dfrac{1}{P}$ $(T=constant)$

$$\boxed{PV = constant}$$

Charles's Law

The volume of a given mass of a gas directly proportional to its absolute temp at constant pressure.

i.e. $V \alpha T$ $(P=constant)$

$$\boxed{\dfrac{V}{T} = Constant}$$

Ideal gas Law

From boyle's law PV=C

Charle's law $\dfrac{V}{T} = C$

Combining both the law

$$\dfrac{PV}{T} = C$$

i.e. $\boxed{PV \alpha T}$

$\boxed{PV = RT}$ .....(i)

This equation is called characteristic gas equation or ideal gas equation.

R= characteristic gas consant

= 0.287 KJ / Kg-k (for atm. air)

Universal gas constant (Ru).

In general PV= mRT (m=mass of gas)

But m = nM

n = no of kg moles

M = Molecular mass of the gas

.. PV = nMRT

= n (MR)T = nR_uT….

R_u = universal gas constant = M.R

M.R = constant of all the gases.

$\boxed{R_u = 8.3143 \text{ KJ/ Kgk}}$

Avogadro's law :

It states that the equal volumes of different ideal gases at the same temperature & pressure contains equal number of molecules.

$$n = \frac{m_1}{M_1} = \frac{m_2}{M2} = \frac{m_3}{M_3} \ldots$$

$$but\, M = \rho v$$

$$n = \frac{\rho 1}{M_1} = \frac{\rho 2}{M_2} = \frac{\rho 3}{M_3}$$

$$\rho = Mass\, density = \frac{1}{V}$$

$$V = Specific\;volume$$

$$n = \frac{1}{M_1\,V_1} = \frac{1}{M_2\,V_2} = \frac{1}{M_3\,V_3} \ldots$$

$$M_1 V_1 = M_2 V_2 = M_3 V_3 = Cons\, tan\, t$$

SP volume molecular weight = Molar volume

$$\boxed{V.M = \overline{V}}$$

Dalton's law :

(i)   The pressure of a mixture of gasses is equal to the sum of the partial pressure of the constituents.

(ii)   The partial pressure of each constituent is that pressure which the gas would exact if it occupied alone at that given volume occupied by the mixture at the same temperature.

$$\boxed{P = P_A + P_B}$$

(iii)   It is found the dalton's law is more accurately by gas mixtures at low pressure.

$$P = P_A + P_B + \ldots\ldots P_n = \Sigma P_i$$

P_i = Partial pressure of the constituent.

Work done in moving the boundaries of a closed system
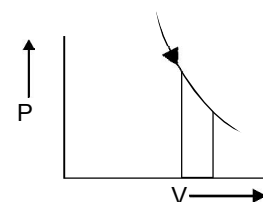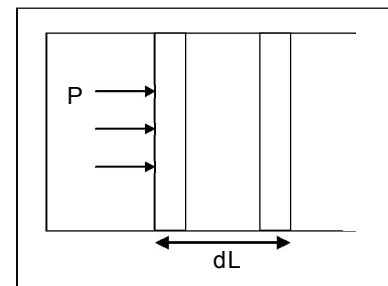
Consider a gas of contained in a piston-cylinder arrangement pressure exerted by the gas is P on the cross sectional area of piston A.

Let the piston moves a distance dl

Work done   = Force x displacement

$$= (P.A) \times dL \qquad \left(P = \frac{F}{A}\right)$$

$$= P.\, dv \qquad (A.dL = dv)$$

Suppose, gas expands from 1 to 2

the W.D = $\int_{V_1}^{V_2} P.dv$

W.D by the system is +ve
W.D on the system is –ve

Constant volume process

W.D = P. dv = 0

dw = 0

$dQ = MC_v = dT$ (heat supplied)

According to 1st law of thermodynamics

$dQ - dw = du$

$MC_v.dT - 0 = du$

$$\boxed{\Delta U = MC_v (T_2 - T_1) \ \text{(Isochoric process)}}$$
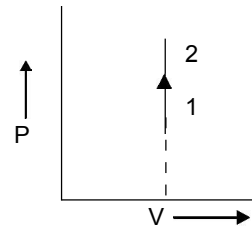
Constant pressure process (Isobaric process)

$dw = \int_1^2 Pdv$

$= P(V_2 - V_1)$

$= P_2V_2 - P_1V_1 = MR(T_2 - T_1)$

$\because P_2 = P_1 = P$

$dQ = \int_1^2 mC_P dT$

$= mC_P (T_2 - T_1)$

$dU = mC_P (T_2 - T_1) - mR(T_2 - T_1)$

$= mC_V (T_2 - T_1)$

$\because C_P - C_V = R$
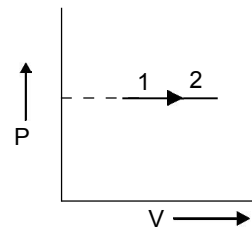
Constant tempretaure process (Isothermal process)

$PV = C$

$P = C / V$

$dw = \int_{V_1}^{V_2} Pdv$

$= \int_{V_1}^{V_2} \frac{C}{V} dv$

$= C[lnv]_{V_1}^{V_2}$

$= C(lnv_2 - lnv_1)$

$= Cln\left(\frac{V_2}{V_1}\right) = P_1V_1 ln\left(\frac{V_2}{V_1}\right) = P_2V_2 ln\left(\frac{V_2}{V_1}\right)$

$= mRTln\left(\frac{V_2}{V_1}\right)$

$dU = mC_V (T_2 - T_1) = 0$

$\because T_2 = T_1$

$Q - W = \Delta U = U_2 - U_1$

$$\boxed{Q = W}$$
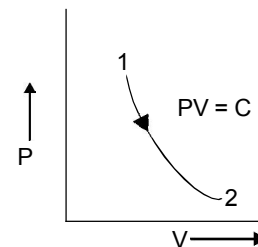
Isentropic process

No heat transfer between the system & the surrounding.

Constant pressure process (Isobaric process)

$PV^\gamma = C$

$$dw = \int_1^2 P.dv = C \int_{V_1}^{V_2} \frac{dv}{V^\gamma}$$

$$= C \left(\frac{V^{-\gamma+1}}{V^{-\gamma+1}} \right)_{V_1}^{V_2}$$

$$= \frac{C}{1-\gamma} \left(P_2 V_2^\gamma . V_2^{1-\gamma} - P_1 V_1^\gamma . V_1^{1-\gamma} \right)$$

$$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \left(C = P_1 V_2^\gamma = P_2 V_2^\gamma \right)$$

$Q = 0$

$$\boxed{\Delta U = W}$$
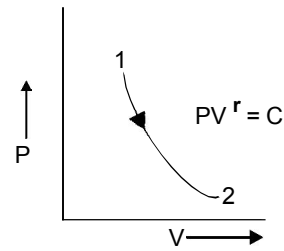
Vender walls equation

$$\left(P + \frac{a}{v^2} \right)(v - b) = RT$$

a,b = Specific constant & depend upon the type of the fluid.

V = volume per unit mass, R = gas constant.

If volume of 1 mole is considered

$$\left(P + \frac{a}{v^2} \right)(\bar{v} - b) = R_0 T$$

$P, \bar{V}, T, R, a, b$ units are as follows

$$P = \frac{N}{M^2}, \bar{V} = \frac{M^3}{kg-k}, T = K, R = \frac{8314 NM}{kgmol - k}$$

$$a, b = \frac{NM^4}{(kgmol)^2}, b = \frac{M^3}{kg}$$

Difference between Real gas & Ideal gas

Real gas	Ideal gas
(i) No gas flows all conditions of gas law under certain conditions of pressure & temperature but it approaches the ideal gas behavior. Hence it is called real gas.	(i) A gas which obeys all the laws of gas under all conditions of temperature & pressure.
(ii) The relations derived from ideal gas may be applied to real gases under certain condition.	(ii) Ideal gas law is simple & hence simple relations are derived from it.
(iii) In certain condition real gas no more remain in gaseous phase but changes its state. So real gases under certain condition behaves like ideal gas.	(iii) O2, N2, H2 may be treated as ideal gas because ordinarily these are difficult to liquefy.

[33]

CHAPTER-7.0.

INTERNAL COMBUSTION ENGINE

Introduction

As the name implies or suggests, the internal combustion engines (briefly written as I.C engine) are those engines in which the combustion of fuel takes place inside the engine cylinder. These are petrol, diesel, and gas engines. We have seen in steam engines or steam turbines that the fuel, fed into the cylinder, is in the form of steam which is already heated (or superheated), and is ready for working in the combustion cycle of the engine. But, in case of internal combustion engines the combustion of fuel takes place inside the engine cylinder by a spark and produces very high temperature.

7.1. Four stroke Cycle Petrol Engine

It is also known as Otto cycle. It requires four strokes of the piston to complete one cycle of operation in the engine cylinder. The four stroke of a petrol engine sucking fuel air mixture (petrol and Air operation with proportionate quantity of air in the carburetor known as charge) are described below :

1. Suction or charging stroke

In this stroke, the inlet valve opens and charge is sucked into the Cylinder as the piston moves downward from top dead centre (T.D.C). It continues till the piston reaches Its bottom dead centre (B.D.C) as show in Fig. 7.1 (a).

2. Compression stroke

In this stroke, both the inlet and exhaust valves are closed and charge is compressed as the piston moves upwards from B.D.C. to T.D.C. As a result of compression the pressure and temperature of the charge increases considerably (the actual values depend upon compression ratio). This completes one revolution of the crankshaft. The compression stroke is showing in Fig. 7.1 (b).

(a) Suction or charging stroke.   (b) Compression stroke.   (c) Expansion or working stroke.   (d) Exhaust stroke.

Fig. 7.1 Four stroke Cycle Petrol Engine

3. Expansion or working stroke

Shortly before the piston reaches T.D.C. (during compression stroke), the charge is ignited with the help of a spark plug. It suddenly increases the pressure temperature of the products of combustion but the volume, practically, remains constant. Due to rise in pressure, the piston is pushed down with a great force. The hot burnt gases expand due high speed of the piston. During this expansion, some of the heat energy produced is transformed mechanical work. It may be noted that during this working stroke, as shown in Fig. 7.1 (c), both valves are closed and piston moves from T.D.C. to B.D.C.

6. Exhaust stroke

1n this stroke, the exhaust valve is open as piston moves from B.D.C to T.D. C. This movement of the piston pushes out the products of combustion, from the engine cylinder and are exhausted through the exhaust valve into the atmosphere, as shown in Fig. 7.1 (d). The completes the cycle, and the engine cylinder is ready to suck the charge again.

Note : The four stroke cycle petrol engine are usually employed in light vehicles such as cars, jeeps, aero planes

7.1.1. Four stroke Cycle Diesel Engine

It is also known as compression ignition engine because the ignition takes place due to the compression produced in the engine cylinder at the end of compression stroke. The four strokes of a diesel diesel engine sucking pure air are described below :

1. Suction or charging stroke

In this stroke, the inlet valve opens and pure air is sucked into the cylinder as the piston moves downwards from the top dead centre {TDC). It continues till the piston reaches its bottom dead centre {BDC) as shown in Fig. 7.2 (a).

2. Compression stroke

In this stroke, both the valves are closed and the air is compressed as the piston moves upwards from BDC to TDC. As a result of compression, pressure and temperature of the air increases considerably (the actual value depends upon the compression ratio). The completes one revolution of the crank shaft. The compression stroke is shown in Fig. 7.2 (b).
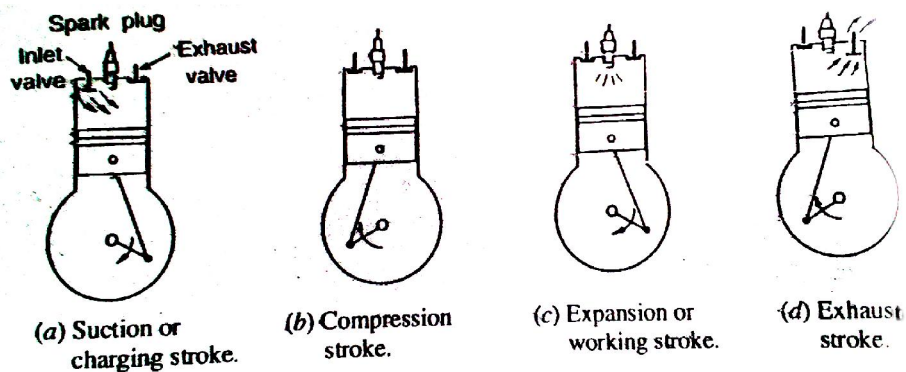

(a) Suction or charging stroke. *(b)* Compression stroke. *(c)* Expansion or working stroke. *(d)* Exhaust stroke.
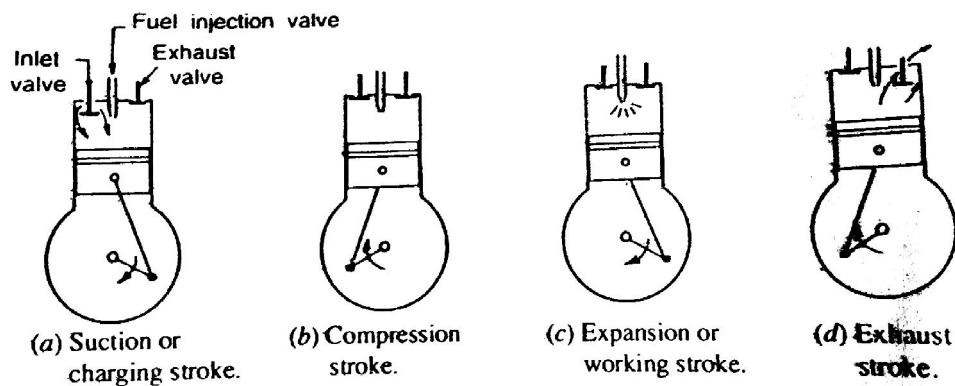
Fig. 7.2 Four stroke Cycle Diesel Engine

3. Expansion or working stroke

Shortly before the piston reaches the TDC (during the compression stroke), fuel oil is injected in the form of very fine spray into the engine cylinder, through the nozzle, known as fuel injection valve. At this moment, temperature of the compressed air sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature of the producer of combustion. The fuel oil is continuously injected for a fraction of the revolution. The fuel oil assumed to be burnt at constant pressure. Due to increased pressure, the piston is pushed down with a great force. The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy is transformed into mechanical work. It may be noted that during this working stroke, both the valves are closed and the piston moves from TDC to BDC.

5. Exhaust stroke

In this stroke, the exhaust valve is open as the piston moves from BDC to TDC. This movement of the piston pushes out the products of combustion from the engine cylinder through the exhaust valve into the atmosphere. This completes the cycle and the engine cylinder ready to suck the fresh air again.

Note : The four stroke cycle diesel engines are generally employed in heavy vehicles such as buses, tucks, tractors, pumping sets, diesel locomotives and in earth moving machinery.

7.1.2. Two-stroke Cycle Petrol Engine

A two-stroke cycle petrol engine was devised by Duglad Clerk in 1880. In this cycle, the suction, compression, expansion and exhaust takes place during two strokes of the piston. It means that there is one working stroke after every revolution of the crank shaft. A two stroke engine has ports instead of valves. All the four stages of a two stroke petrol engine are described below :

1. Suction stage

In this stage, the piston, while going down towards BDC, uncovers both the transfer port and the exhaust port. The fresh fuel-air mixture flows into the engine cylinder from the crank case, as shown in Fig. 7.3 (a).

2. Compression stage

In this stage, the piston, while moving up, first covers the transfer port and then exhaust port. After that the fuel is compressed as the piston moves upwards as shown in Fig.7.3 (b) in this stage, the inlet port opens and fresh fuel-air mixture enters into the crank case.

(a) Suction   (b) Compression   (c) Expansion   (d) Exhaust

Fig. 7.3 Two-stroke Cycle Petrol Engine

3. Expansion stage

Shortly before this piston reaches the TDC (during compression stroke, the charge is ignited with the help of a spark plug. It suddenly increases the pressure and temperature of the products of combustion. But the volume, practically, remains constant. Due to rise of the pressure the piston is pushed downwards with a great force as shown in Fig. 7.3 (c). The burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy produced is transformed into mechanical work.

4. Exhaust stage

In this stage, the exhaust port is opened as the piston moves downwards, products of combustion, from the engine cylinder are exhausted through the exhaust port into atmosphere as shown in Fig. 7.3 (d). This completes the cycle and the engine cylinder is ready for the charge again.

Note : Two stroke petrol engines are generally employed in very light vehicles such as scooters, motor cycles, and sprayers.

7.1.3. Two-stroke Cycle Diesel Engine

A two-stroke cycle diesel engine also has one working stroke after every revolution of the crank shaft. All the four stages of a two stroke cycle diesel engine are described below :

1. Suction stage

In this stage, the piston while going down towards BDC uncovers the transfer port and the exhaust port. The fresh air flows into the engine cylinder from the crank case as shown in Fig. 7.4 (a).

2. Compression stage

In this stage, the piston while moving up, first covers the transfer port and then exhaust port. After that the air is compressed as the piston moves upwards as shown Fig. 7.4 (b). In this stage, the inlet port opens and the fresh air enters into crank case.
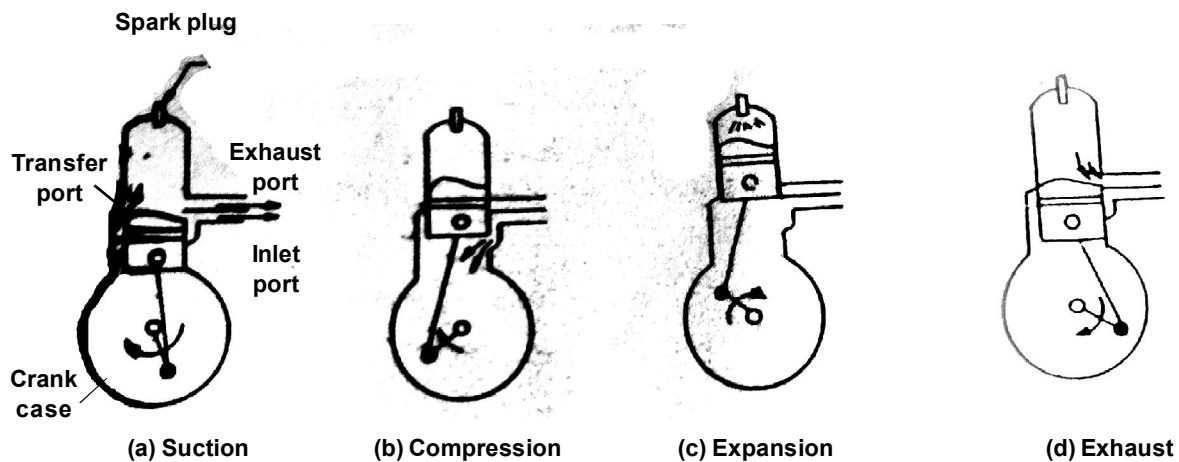

(a) Suction　　(b) Compression　　(c) Expansion　　(d) Exhaust
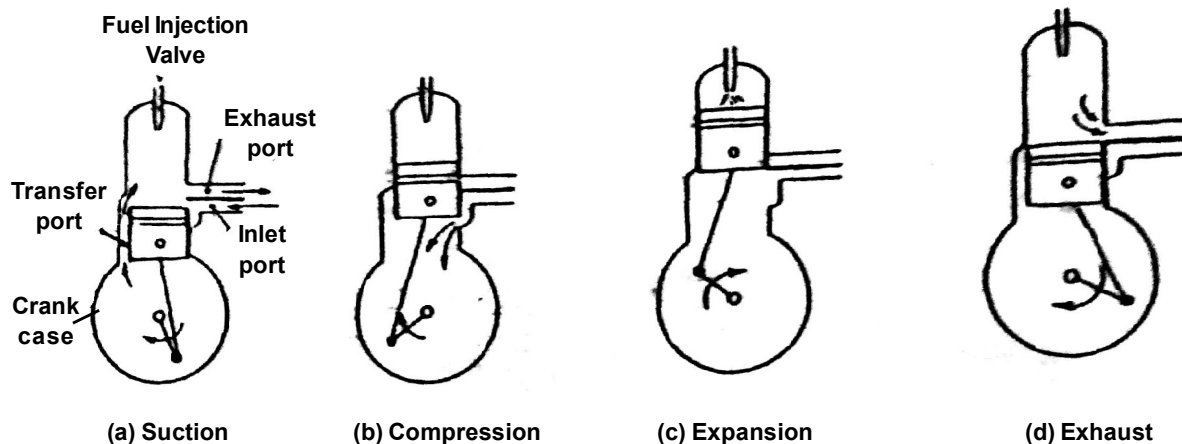
Fig. 7.4 Two-stroke Cycle Diesel Engine

3. Expansion stage

Shortly before the piston reaches the TDC (during compression stroke) the fuel oil is injected in the form of very fine spray into the engine cylinder through the nozzle shown as fuel injection valve, as shown in fig. 7.4 (c). At this moment, temperature of the compressed air is sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature of the products of combustion. The fuel oil is continuously injected for a fraction of the crank rotation. The fuel oil is assumed to be burnt at constant pressure. Due to increased pressure, the piston is pushed with a great force. The hot burnt gases expand due to high speed of the piston. During expansion some of the heat energy produced is transformed into mechanical work.

4. Exhaust stage

In this stage, the exhaust port is opened and the piston moves downwards. The products of combustion from the engine cylinder are exhausted through the exhaust port into the atmosphere as shown in Fig. 7.4 (d). This completes the cycle, and the engine cylinder is ready to suck the air again.

Notes : Two stroke diesel engines are mainly used in marine propulsion where space and lightness are the main considerations.

7.2. Difference between two stroke and four stroke cycle engine.

In a two-stroke engine, the working cycle is completed in two strokes of the piston or one revolution of the crankshaft. This is achieved by carrying out the suction and compression process in one stroke (or more precisely in inward stroke), expansion and exhaust processes in the second stroke (or more precisely in outward stroke). In a four-stroke engine, the working cycle is completed in four-strokes of the piston or two-revolutions of the crankshaft. This is achieved by carrying suction, compression, expansion and exhaust processes in each stroke.

It will be interesting to know that from the thermodynamic point of view, there is no difference between two-stroke and four-stroke cycle engines. The difference is purely mechanical which are as follows :

1. A two stroke cycle engine gives twice the number of power strokes than the four stroke cycle engine at the same engine speed. Theoretically, a two-stroke cycle engine should develop twice power as that of a four-stroke cycle engine. But in actual practice, a two-stroke cycle engine develops 1.7 to 1.8 times (greater value for slow speed engines) the power developed by four-stroke cycle engine of the same dimensions and speed. This is due to lower compression ratio and effect stroke being less than the theoretical stroke.

2. For the same power developed, a two-stroke cycle engine is lighter, less bulky and occupies less floor area. Thus it makes, a two-stroke cycle engine suitable for marine engine other light vehicles.

3. As the number of working strokes in a two-stroke cycle engine are twice than four-stroke cycle engine, so the turning moment of a two-stroke cycle engine is more uniform. So it makes a two-stroke cycle engine to have a lighter flywheel and foundations. This also leads to higher mechanical efficiency of a two-stroke cycle engine.

4. The initial cost of a two-stroke cycle engine is considerably less than a four-stroke cycle engine.

5. The mechanism of a two-stroke cycle engine is much simpler than a four-stroke cycle engine

6. The two-stroke cycle engines are much easier to start.

7. Thermal efficiency of a two-stroke cycle engine is less than that a four-stroke cycle engine because a two-stroke cycle engine has less compression ratio than that of a four-stroke cycle engine

8. Overall efficiency of a two-stroke cycle engine is also less than that of a four-stroke cycle engine because in a two-stroke cycle, inlet and exhaust ports remain open simultaneously for sometime. Inspite of careful design, a small quantity of charge is lost from the engine cylinder.

9. In case of a two-stroke cycle engine, the number of power strokes are twice as those of fourstroke cycle engine. Thus the capacity of the cooling system must be higher. Beyond a certain limit, the cooling capacity offers a considerable difficulty. Moreover, there is a greater wear and in a two-stroke cycle engine.

10. The consumption of lubricating oil is large in a twp-stroke cycle engine because of the high operating temperature.

11. The exhaust gases in a two-stroke cycle engine creates noise, because of short time available for their exhaust.

7.2.1. Difference between petrol and diesel engine.

Following points are important for the comparison of petrol engines and diesel engine

Petrol Engines	Diesel Engines
1. A petrol engine draws a mixture of petrol and air during suction stroke.	A diesel engine draws only air during suction stroke.
2. The carburetor is employed to mix air and petrol in the required proportion and to supply it to the engine during suction stroke.	The injector or atomiser is employed to inject fuel at the end of compression stroke.
3. Pressure at the end of compression is about 10 bar.	Pressure at the end of compression is about 35 bar.
4. The charge (i.e. petrol and air mixture) is ignited with the help of spark plug.	The fuel is injected in the form of fine spray. The temperature of the compressed air (about 600^0C at a pressure of about 35 bar) is sufficiently able to ignite the fuel.
5. The combustion of fuel takes place approximately at constant volume. In other words, it works on Otto cycle.	The combustion of fuel takes place approximately at constant pressure. In other words, it works on Diesel cycle.
6. A petrol engine has compression ratio approximately from 6 to 10.	A diesel engine has compression ratio approximately from 15 to 25.
7. The starting is easy due to low compression ratio.	The starting is little difficult due to high compression ratio.
8. As the compression ratio is low, the petrol engines are lighter and cheaper.	As the compression ratio is high, the diesel engines are heavier and costlier.
9. The running cost of a petrol engine is high because of the higher cost of petrol.	The running cost of diesel engine is low because of the lower cost of diesel.

Petrol Engines	Diesel Engines
10. The maintenance cost is less.	The maintenance cost is more.
11. The thermal efficiency is upto about 26%.	The thermal efficiency is upto about 40%.
12. Overheating trouble is more due to low thermal efficiency.	Oveheating trouble is less due to high thermal efficiency.
13. These are high speed engines.	These are relatively low speed engines.
14. The petrol engines are generally employed in light duty vehicles such as scooters, motorcycles, cars. These are also used in aeroplanes.	The diesel engines are generally employed in heavy duty vehicles like buses, bucks, and cars moving machines etc.

① Define fuel.

Fuel is a substance that is burned to provide heat & energy. The energy which releases is generally in the form of chemical energy or heat energy. Now nuclear energy is also released due to nuclear fission or fusion.
    EXP:- petrol, diesel, coal, Natural gas, hydrogen, bio diesel.

② Types of fuel

① Solid fuel   ② Liquid fuel   ③ gaseous fuel

Solid fuels

These are solid materials that combust to produce energy.
EXP: wood, coal, charcoal, soot.

Liquid fuels

These are the fuels we burn to produce mechanical energy & K.E. most liquid fuel

such as crude oil form due to exposure to intense heat & pressure to fossilized remains of Plants & animals. Then there are biofuels in liquid form such as ethanol & hydrogen fuel. These fuel are easy to transport and relatively easy to use.

3 principal liquid fuels are benzyl, alcohol, and petroleum products.

Gaseous fuel

These fuels are in a gaseous state under normal conditions. Some examples are methane, Carbon monoxide, propane etc. They have an advantage that they can be easily food transported to the place of consumption. However They also tend to leak from pipes & precautions are taken to avoid this. The best example is the CNG gas that comes to kitchen via pipes that we utilize for cooking.

Exp:- coal gas, Town gas, producer gas, water gas, Blast furnace gas.

soled fuels & their characteristics

→ They are easy to transport
→ they are convenient to store without any risk of spontaneous explosion
→ Their cost of production is low.

→ They possess moderate ignition tempt.

P), advantages

→ their ash content is high.

→ Their large proportion of heat is wasted.

→ Their combustion operation can not be controlled easily.

→ Their cost of handling is high.

Liquid fuels & their characteristics

Advantages

→ They possess higher calorific value per unit mass than solid fuels.

→ They burn without dust, ash etc.

→ Their firing is easier & also fire can be extinguished easily by stopping the liquid fuel supply.

→ They are easy to transport through pipes.

→ They can be stored indefinitely without any loss.

→ They are clean in use & economic to handle.

→ Loss of heat in chimney is very low due to greater cleanliness.

→ They require less excess air for complete combustion

→ They require less furnace space for combustion.

Disadvantages

→ The cost of liquid fuel is relatively much higher as compared to solid fuel.

→ costly special storage tanks are required for storing liquid fuels.

→ There is greater risk of fire hazards, particularly in case of highly inflammable and volatile liquid fuels.

→ They give bad odour.

→ for efficient burning of liquid fuels, specially constructed burners and spraying apparatus are required.

Gaseous fuels & their characteristics

Advantages

→ They can be conveyed easily through pipelines to the actual place of need, thereby eliminating manual labour in transportation.

→ They can be lighted at ease.

→ They have high heat contents & help us in having higher tempt.

→ They can be preheated by the heat of hot waste gases, thereby affecting economy in heat.

→ their combustion can be easily controlled

→ They are clean in use without having any ash, smoke or shoot.

→ They donot require special burner.

Disadvantages

→ very large storage tanks are needed.

→ They are highly inflammable, so chances of fire hazards in their use is high.

③ **calorific value of fuel / heating value of fuel**

It is defined as the heat liberated in KJ by complete combustion of 1kg of fuel (solid or liquid). For gaseous fuel calorific value is in KJ per cubic meter of gas at S.T.P.

calorific value

higher calorific value   Lower calorific value.

higher calorific value

When the product of combustion are cooled to 25°C, practically all the water vapour resulting from the combustion process is condensed. The heating value thus obtained

is called higher calorific value or gross calorific value.

Lower calorific value
It is the heat released when water vapour in the products of combustion is not condensed and remains in the vapour form.

④ Quality of I.C. engine fuels.
Normally fuels are rated for their antiknock qualities. The ratings of fuel is done by two parameters called octane number for S.I. engine and cetane number for C.I. engine fuels.

octane Number.
It is defined as the percentage, by volume, of iso octane in a mixture of iso octane & normal heptane, which exactly matches the Knocking intensity of the fuel in a standard engine under a set of standard operating condition.

Iso-octane is assigned a rating of 100 octane number
but normal heptane is given a rating of '0' octane number.

cetane Number
It is defined as the percentage by volume of normal cetane ($C_{16}H_{34}$) and α-methyl naphthalene ($C_{11}H_{10}$) which has same ignition

characteristics (ignition delay) as the test fuel when combustion is carried out in a standard engine under specified operating condition.

→ Normal cetane ($C_{16}H_{34}$) is assigned a cetane number of 100

→ α-methyl ~~naph~~ Naphthalene is assigned a cetane number of 0.