LECTURE NOTES

ON

THERMAL ENGINEERING-I

PREPARED BY

SUPRAVA BEHERA, LECTURER

DEPARTMENT OF MECHANICAL ENGINEERING

GOVT. POLYTECHNIC, JAJPUR-755019

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Chapter-1

Thermodynamic concept & Terminology

INTRODUCTION:

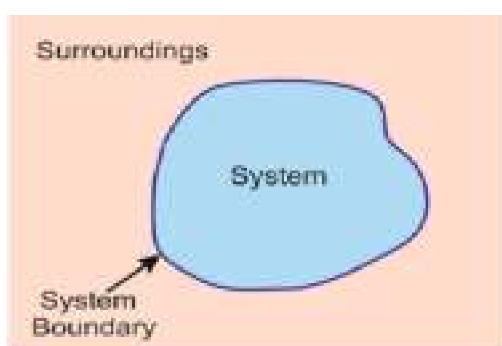
- Thermodynamics is the science that deals with heat and work and those properties of substance that bear a relation to heat and work.
- Thermodynamics is the study of the patterns of energy change. Most of this course will be concerned with understanding the patterns of energy change.
- More specifically, thermodynamics deals with (a) energy conversion and (b) the direction of change.

  Basis of thermodynamics is experimental observation. In that sense it is an empirical science. The principles of thermodynamics are summarized in the form of four laws known as zeroth, first, second, and the third laws of thermodynamics.
- Thermodynamics comes from two greek words Thermi & Dynamic. Thermi means heat & dynamic means power or work by motion.

Macroscopic and Microscopic Approaches:

- Microscopic approach uses the statistical considerations and probability theory, where we deal with "average" for all particles under consideration. This is the approach used in the disciplines known as kinetic theory and statistical mechanics.
- In the macroscopic point of view, of classical thermodynamics, one is concerned with the time-averaged influence of many molecules that can be perceived by the senses and measured by the instruments. The pressure exerted by a gas is an example of this. It results from the change in momentum of the molecules, as they collide with the wall. Here we are not concerned with the actions of individual molecules but with the time-averaged force on a given area that can be measured by a pressure gage.
- From the macroscopic point of view, we are always concerned with volumes that are very large compared to molecular dimensions, and therefore a system contains many molecules, and this is called continuum. The concept of continuum loses validity when the mean free path of molecules approaches the order of typical system dimensions.

Thermodynamic systems:



A Thermodynamic system is defined as the fixed mass or fixed region in space upon which our study is focused. A specified region in a space upon which attention is focused for thermodynamic analysis is known as a system.

We introduce boundaries in our study called the system and surroundings. The boundaries are set up in a way most conducive to understanding the energetics of what we're studying. Defining the system and surroundings is arbitrary, but it becomes important when we consider the exchange of energy between the system and surroundings.

Surroundings: Everything external to the system is called Surrounding.

Boundary: It is a real or imaginary surface which separates system from the surroundings. A boundary can be fixed or movable. A boundary has no thickness, no mass and no volume.

Two types of exchange can occur between system and surroundings:

(1) energy exchange (heat, work, friction, radiation, etc.) and,

(2) matter exchange (movement of molecules across the boundary of the system and surroundings).

Based on the types of exchange which take place or don't take place, we will define three types of systems:

- **Isolated systems**: no exchange of matter or energy.
- **Closed systems**: no exchange of matter but some exchange of energy.
- **Open systems**: exchange of both matter and energy.

Thermodynamic Property :

In thermodynamics a property is any characteristic of a system that is associated with the energy and can be quantitatively evaluated.

- The property of a system should have a definite value when the system is in a particular state.
- Thermodynamic property is a point function.
- Properties like volume of a system that depend on the mass of a system are called extensive properties.
- Properties like pressure or temperature which do not depend on the system mass are called intensive properties.
- The ratio of extensive property to the mass of the system are called specific properties and therefore become intensive properties.
- Substance can be found in three states of physical aggregation namely, solid, liquid and vapor which are called its phases.
- If the system consists of mixture of different phases, the phases are separated from each other by phase boundary.
- The thermodynamic properties change abruptly at the phase boundary, even though the intensive properties like temperature and pressure are identical.

Pressure (p):

A fluid exerts on a surface element dS of a wall a force of pressure perpendicular to dS, directed outwards with a norm equal to p dS, where by definition p is the pressure of the fluid.
Pressure is defined as force acting per unit area.
SI unit is the Pascal(N/M^2).

Temperature (T):

Temperature is a measure of the average kinetic energy of the atoms or molecules in the system. The unit of measurement in the International System of Units (SI) is the kelvin.

Temperature is measure of hotness or coldness in a substance.

The basic units (SI Units)

- Mass kg.
- Mole The mole is the amount of substance that contains as many atoms (or molecules) as there are atoms in 0.012 kg of carbon-12.
- Length—m.
- Time: second (s)
- SI unit of temperature is Kelvin (abbreviated as K). The Kelvin is defined as the fraction of 1/273.16 of the thermodynamic temperature of the triple point of water. The relation between Kelvin and Celsius temperature is K = C + 273.15 (The triple point of water is at 0.01 C).
- Force: 1 N = 1 kg m/s,
- Pressure, 1 Pa = 1 N/m^2 , 1 bar = 10^5 Pa, 1 atm. = 101.325 KPa.= 760 mm of HG
  In thermodynamics we are concerned with absolute pressure.
  Gauge pressure = absolute pressure – atmospheric pressure.
  Ordinary vacuum gauge pressure = atmospheric pressure – absolute pressure.

Volume (V):

The volume of a thermodynamic system typically refers to the volume of the working fluid, such as, for example, the fluid within a piston. Changes to this volume may be made through an application of work, or may be used to produce work. **SI unit of volume is M^3.**

Internal Energy :

• The molecule as a whole can move in x, y and z directions with respective components of velocities and hence possesses kinetic energy.

• There can be rotation of molecule about its center of mass and than the kinetic energy associated with rotation is called rotational energy.

• In addition the bond length undergoes change and the energy associated with it is called vibrational energy.

• The electron move around the nucleus and they possess a certain energy that is called electron energy.

• The microscopic modes of energy are due to the internal structure of the matter and hence sum of all microscopic modes of energy is called the internal energy.

Bulk kinetic energy (KE) and potential energy (PE) are considered separately and the other energy of control mass as a single property (U).

The total energy possessed by the body is given by:

E = KE + PE + U

Intensive & Extensive properties:

- An intensive property is one that does not depend on the mass of the substance or system.
- Temperature (T), pressure (P) and density (r) are examples of intensive properties.

Intensive Property Examples;

The properties of matter that do not depend on the size or quantity of matter in any way are referred to as an intensive property of matter. Temperatures, density, color, melting and boiling point, etc., all are intensive property as they will not change with a change in size or quantity of matter. The density of 1 liter of water or 100 liters of water will remain the same as it is an intensive property.

- An extensive property of a system depends on the system size or the amount of matter in the system.

If the value of the property of a system is equal to the sum of the values for the parts of the system then such a property is called extensive property. Volume, energy, and mass are examples of extensive properties.

Extensive Property Examples;

There are properties such as length, mass, volume, weight, etc. that depend on the quantity or size of the matter, these properties are called an extensive property of matter and their value changes if the size or quantity of matter changes. Suppose we have two boxes made up of the same material, one has a capacity of four litres while the other has a capacity of ten litres. The box with ten litres capacity will have more amount of matter as compared to that of a four-liter box.

Extensive property	Symbol	SI units	Intensive property	Symbol	SI units
Volume	*V*	m^3 *or L*	*Specific volume*	*v*	*m3/kg or L/kg*
Internal energy	*U*	*J*	*Specific internal energy*	*u*	*J/kg*
Entropy	*S*	*J/K*	*Specific entropy*	*s*	*J/(kg·K)*
Enthalpy	*H*	*J*	*Specific enthalpy*	*h*	*J/kg*
Gibbs free energy	*G*	*J*	*Specific Gibbs free energy*	*g*	*J/kg*
Heat capacity at constant volume	C_V	*J/K*	*Specific heat capacity at constant volume*	c_V	*J/(kg·K)*
Heat capacity at constant pressure	C_P	*J/K*	*Specific heat capacity at constant pressure*	c_P	*J/(kg·K)*

Specific properties derived from extensive properties

Thermodynamic process:

A process is path followed by a system in reaching a given final state of equilibrium state starting from a specified initial state.

An actual process occurs only when the equilibrium state does not exist.

An ideal process can be defined in which the deviation from thermodynamic equilibrium is infinitesimal.

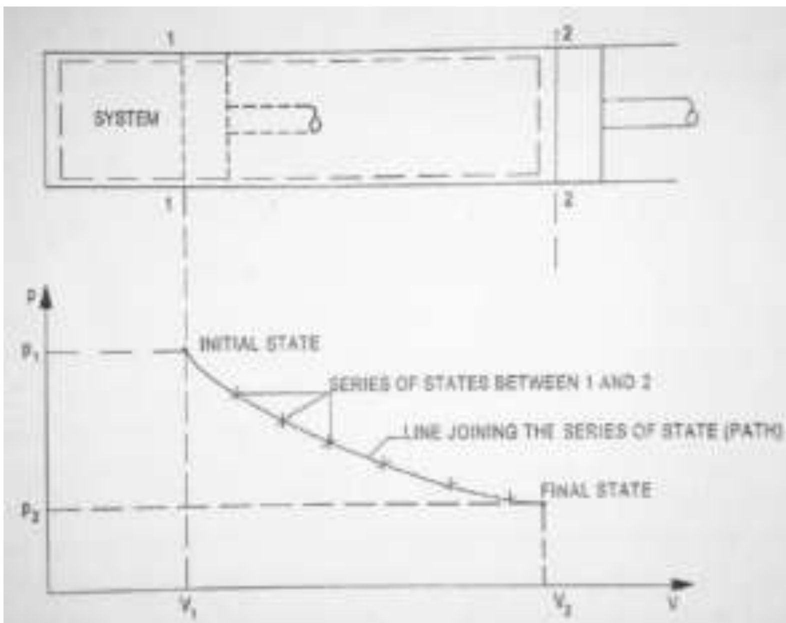
All the states the system passes through during a quasi-equilibrium process may be considered equilibrium states.

For non-equilibrium processes, we are limited to a description of the system before the process occurs and after the equilibrium is restored.

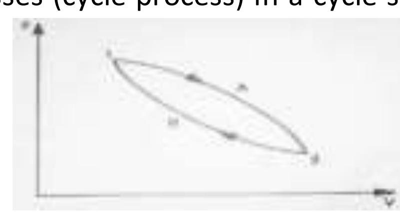
- A process is said to be reversible if both the system and its surroundings can be restored to their respective initial states by reversing the direction of the process.

- **reversible:** if the process happens slow enough to be reversed.
  irreversible: if the process cannot be reversed (like most processes).
- **isobaric**: process done at constant pressure
- **isochoric:** process done at constant volume
- **isothermal:** process done at constant temperature
- **adiabatic**: process where heat transfer is zero.(q=0)
- **cyclic:** process where initial state = final state

Thermodynamic State: A system is said to be exist in a definite state if all the properties of the system (*pressure, temperature, volume etc,*) have fixed values. If any one of the property changes, the system changes to another state.
Example: At 1 atm pressure and 10 degree centigrade water is in solid state (mixed state)
At 1 atm pressure and 110 degree centigrade it is vapour state.
Thermodynamic Path: The series of states passed through by the system during a change from one equilibrium state to another. Change of state of a system is the consequence of any operation in which properties will change. The series of states through which system passes during a change of state is called the path of the process.



Thermodynamic Cycle: Thermodynamics cycle is a process in which initial and final conditions are same. A thermodynamic cycle is defined as a series of process such that the system returns to its initial state. Thus the series of processes (cycle process) in a cycle starts and ends at the same state of a system.



(Figure illustrate the cycle comprising two processes A and B.)

Path function:

A Path function is a function whose value depends on the path followed by the thermodynamic process irrespective of the initial and final states of the process.

An example of path function is work done in a thermodynamic process.

- Work done in a thermodynamic process is dependent on the path followed by the process.
- A path function is an inexact or imperfect differential.

Point function:

A Point function (also known as state function) is a function whose value depends on the final and initial states of the thermodynamic process, irrespective of the path followed by the process.

- Example of point functions are density, enthalpy, internal energy, entropy etc.
- A point function is a property of the system or we can say all the properties of the system are point functions.
- Point functions are exact or perfect differential.

Note: Since a point function is only dependent on the initial or final state of the system, hence in a cyclic process value of a thermodynamic function is zero, or change in thermodynamic property is zero.

Difference between point function and path function:

Sr. no.	Point Function	Path Function
1	Its values are based on the state of the system (i.e. pressure, volume, temperature etc.)	Its values are based on how that particular thermodynamic state is achieved.
2	No matter by which process the state is obtained, its values will always remain the same.	Different processes to obtain a particular state will give us different values.

3	Only initial and final states of the process are sufficient	We need to know exact path followed by the process
4	Its values are independent of the path followed	Its values are dependent on the path followed
5	It is an exact or perfect differential	It is an inexact or imperfect differential.
6	Its cyclic integral is always zero	Its cyclic integral may or may not be zero
7	It is property of the system	It is not the property of the system
8	Its examples are density, enthalpy, internal energy, entropy etc	Its examples are Heat, work etc.

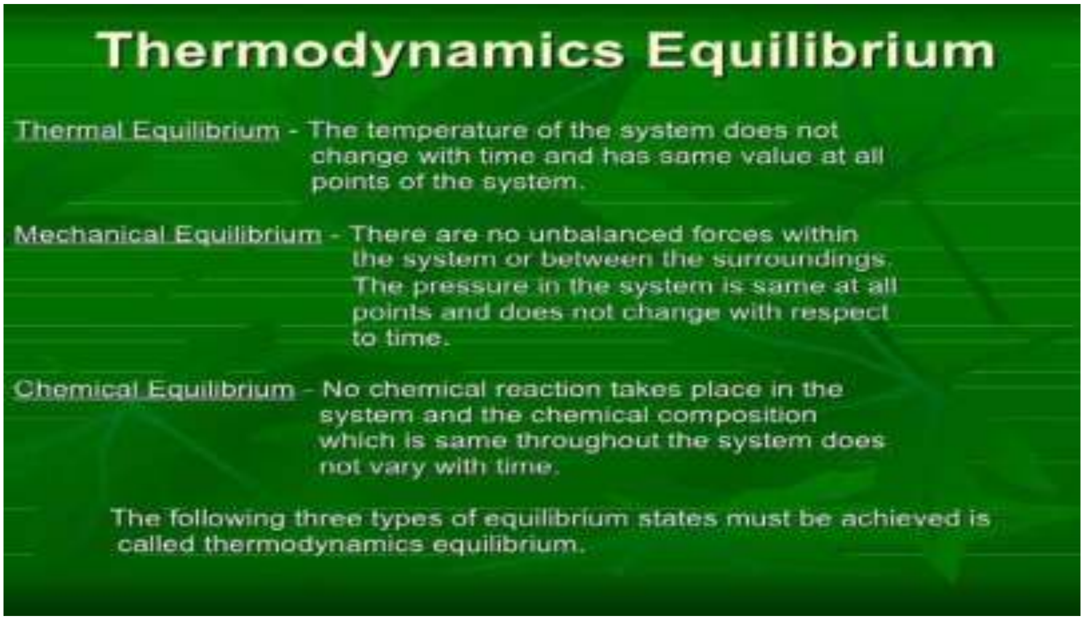
Thermodynamic equilibrium:

The system is said to be thermodynamic equilibrium when there is no spontaneous change in any macroscopic property is observed, as the system is isolated from its surroundings is known as thermodynamic Equilibrium.

When the property of a system is defined, it is understood that the system is in equilibrium.

• If a system is in thermal equilibrium, the temperature will be same throughout the system.

• If a system is in mechanical equilibrium, there is no tendency for the pressure to change. In a single phase system, if the concentration is uniform and there is no tendency for mass transfer or diffusion, the system is said to be in chemical equilibrium.



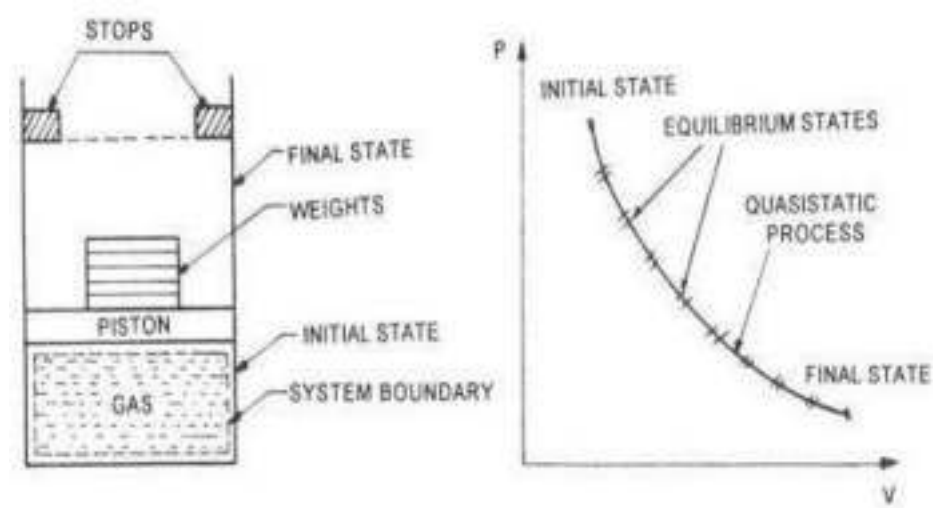
Quasi-static process:

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times: Quasi-static or Quasi-equilibrium process

• The process proceeds slow enough to allow the system to the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.

Engineers are interested in quasi-static processes because – they are easy to analyse – work-producing devices deliver maximum work when they operate on quasi-static processes

• Quasi-static processes serve as standards to which actual processes can be compared.



(Fig. Quasi-static process)

- The quasi-static or quasi-equilibrium process is also known as reversible process. A process which can be reversed in direction and the system retraces the same equilibrium states is known as reversible process.

Energy:

Energy possesses the ability to produce a dynamic, vital effect. Energy exists in various forms. e.g. mechanical, thermal, electrical etc. One form of energy can transform to other by suitable arrangements.

SOURCES OF ENERGY:

The various sources of energy are:

- Fuels- I. Solids-Coal,Coke, Anthracite etc.
  2. Liquids-Petroleum and its derivates
  3. Gases-Natural gas, blast furnace gas etc
- Energy stored in water
- Nuclear energy
- Wind energy
- Solar energy
- Tidal energy
- Geothermal energy
- Thermoelectric power

Power:

Any Physical unit of energy when divided by a unit of time automatically becomes a unit of power. Power can be defined as rate of flow of energy and can state that a power plant is a unit built for production and delivery of flow of mechanical and electrical energy. With the advancement of technology the power consumption is rising steadily.

This necessitates that in addition to the existing source of power such as coal, water, petroleum etc. other source of energy should be searched out and new and more efficient ways of producing energy should be decided.

Work:

The work is said to be done by a force when it acts on a body moving in the direction of force.

Whenever a system interacts with its surroundings, it can exchange energy in two wayswork and heat.

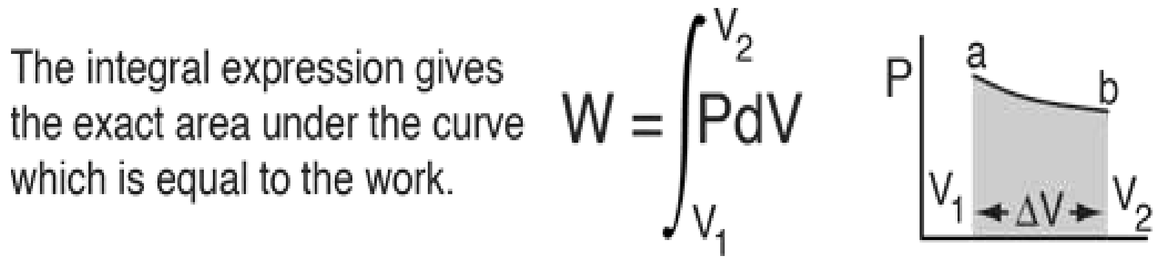
In mechanics, work is defined as the product of the force and the displacement in the direction of the force.

Work done when a volume is increased or decreased Consider a gas in a container with a movable piston on top. If the gas expands, the piston moves out and work is done by the system on the surroundings.

To calculate the work done in moving the piston,

- we know that the**, force = pressure x area** and then,
  work = pressure x area timex distance or, **work = pressure x change in volume**.
  So, **$W = \int p\, dV$**
- The differential work done (dW) associated with a differential displacement (dl) is given by
  $dW = F .dl$
- For a piston cylinder assembly, **$dW = F\, dl = PA\, (dl) = P\, dV$**
- If the gas is allowed to expand reversibly from the initial pressure P to final pressure P, then the work done is given by **$W = \int p\, dV$**

The integral represents the area under the curve on a pressure versus volume diagram. Therefore the work depends on the path followed and work is a path function and hence not a property of the system.
• The above expression does not represent work in the case of an irreversible process.
• The thermodynamic definition of work is *" Work is said to be done by a system on the surrounding if the sole effect external to the system could be reduced to the raising of a mass through a distance".*



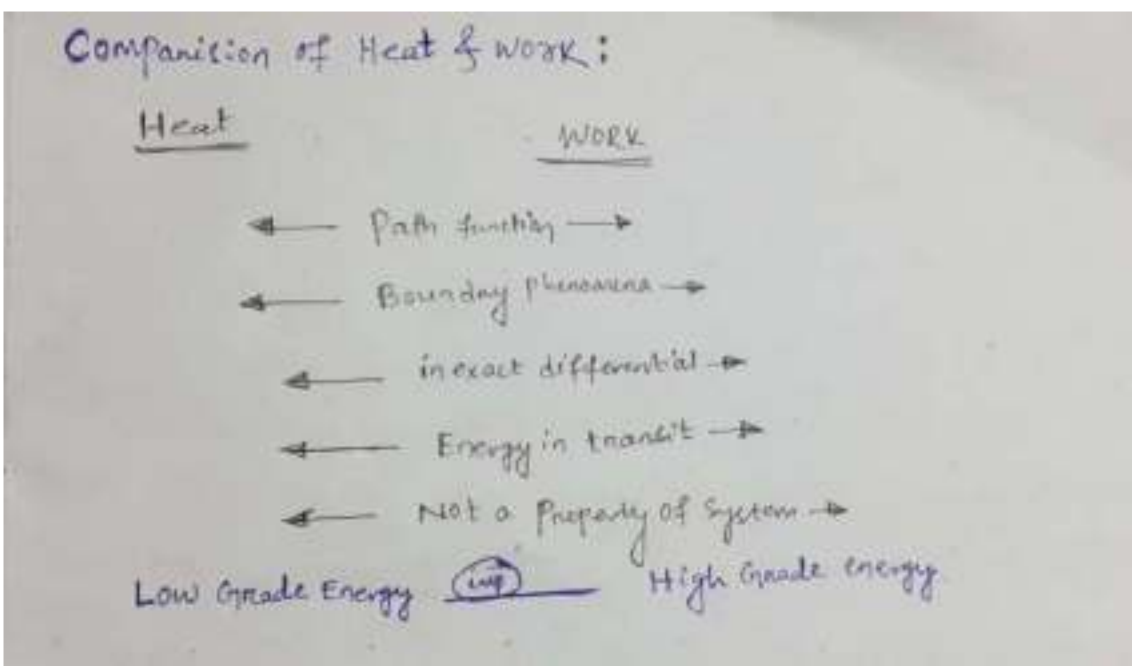
Heat:

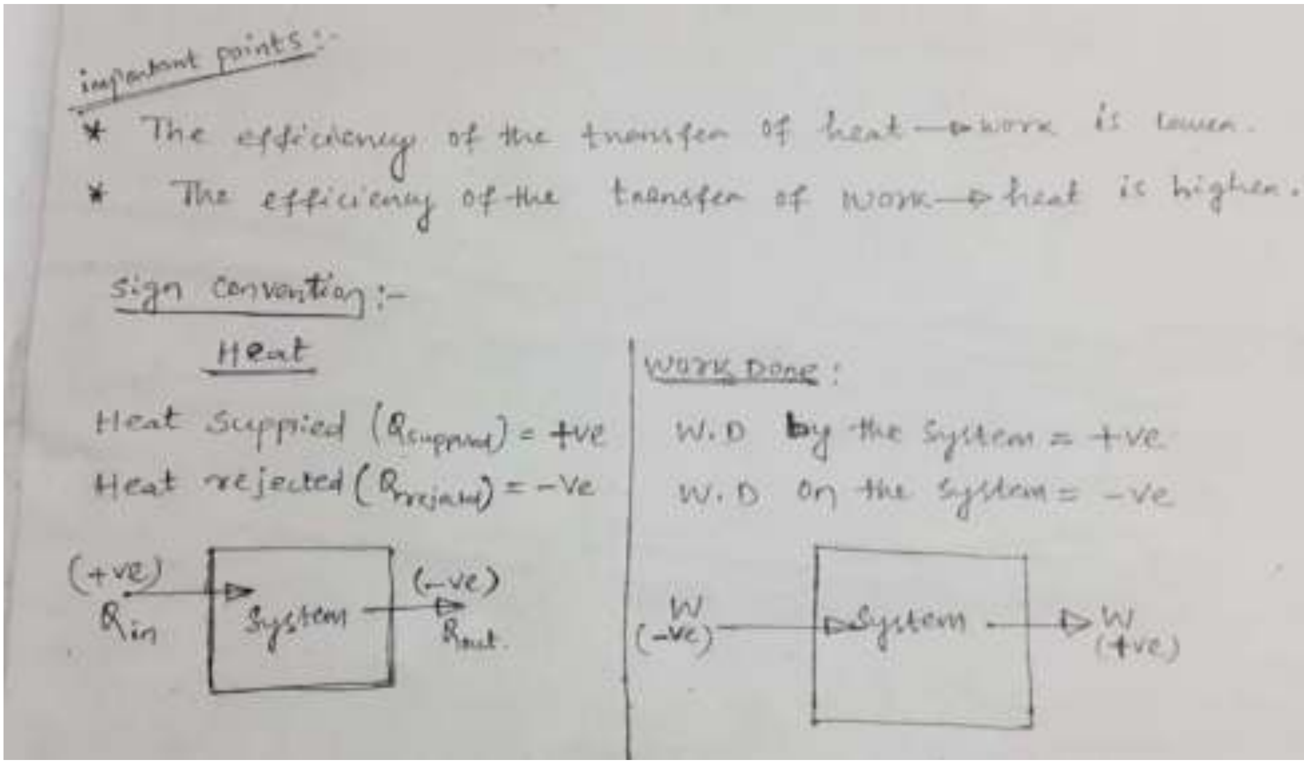
Heat is the mode of energy transfer which takes place by virtue of temperature difference. The direction of spontaneous heat transfer is always from higher temperature to lower temperature. The mode of heat transfer may be in conduction, convection and radiation.

Heat like work, is energy in transit and it can be identified only at the boundary of the system.

- Heat is not stored in the body but energy is stored in the body.
- Heat, like work is not aproperty of the systemand hence it is not an exact differential.
- Thus heat is also a path function and notpoint function.

Comparision of heat and work:





Mechanical equivalent of Heat:

There is a simple relation between mechanical work done on a system and heat generated in it. **James Prescott Joule** first experimentally found that the heat produced in a system is directly proportional to the mechanical work done on it.

He also calculated the constant of proportionality through a unique experiment, which we will also describe in this article. The constant is popularly known as **Mechanical Equivalent of Heat**. After the name of **James Prescott Joule**, the constant is also often known as **Joule's Mechanical Equivalent of Heat** or simply **Joule's Constant**. We denote it with the capital English letter J.

If W is the work done on a system and Q is the quantity of heat produced due to this work, then

$$W \propto Q$$
$$\Rightarrow W = JQ$$
$$\Rightarrow J = \frac{W}{Q}$$

After, this experiment, by putting all known values of

$$J = 4.186 \;\; kJ/kcal$$

Here, in this experiment, the potential energy of the falling mass is converted into the kinetic energy and finally to the heat energy.

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.

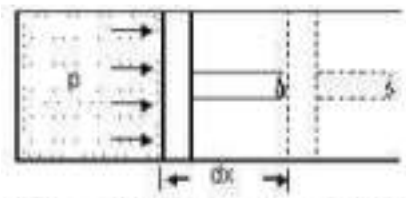


Figure 2.4 Displacement work

Force acting on the piston =Pressure x Area

= p.A

Work done =Force x distance

= pA x dx

= p.dV

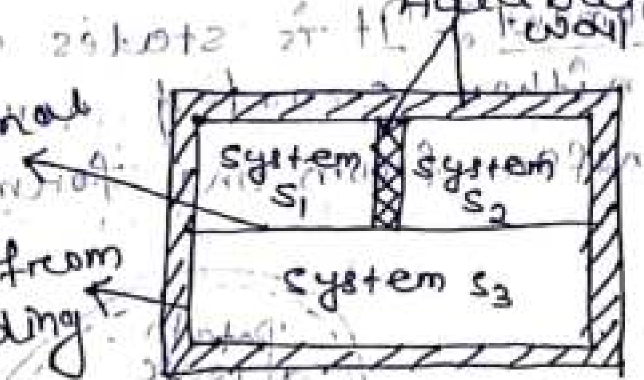
Where, dV =change in volume.

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.

CH-2 Laws of Thermodynamics

Zeroth law of thermodynamics :-

Statement :-



It is state that when two systems are in thermal equilibrium with a third system, then they are in thermal equilibrium with each other.

Consider two systems S_1 & S_2 which are separate by an adiabatic wall, and a third system S_3 is in communication with ~~two~~ both system (S_1 & S_2).

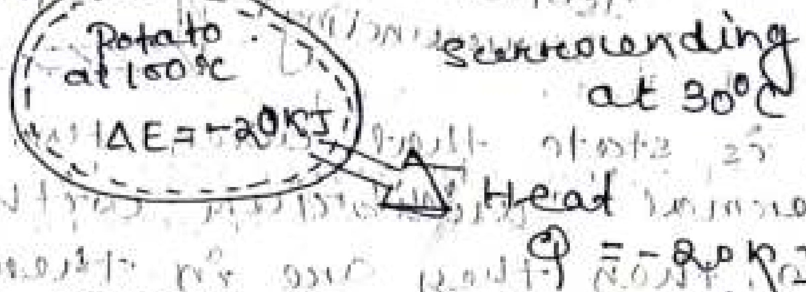
If system S_1 & S_2 are individually in thermal equilibrium with third system then the systems (S_1 & S_2) will be also in thermal equilibrium, even though they are not in contact.

This Zeroth law of thermodynamics serve a basis for the validity of temperature measurement, by replacing the system S_3 by a thermometer.

So, the both system S_1 & S_2 are in thermal equillibrium having same temp.

1st law of Thermodynamics (Conservation of energy principle)

Statement: It is states that the energy can be neither created nor destroyed, it only transfer from one form to another.



→ Consider a process for only heat transfer, but no work interaction.

→ A hot potato is in oven having temperature 100°C, is expose to room air temperature.

As a result of heat transfer from the hot potato, its energy decreases.

So, the decrease of total energy of hot potato is equal to the energy transfer to the surrounding.

From the 1st law of thermodynamics

$-\Delta E = -Q$

$\Rightarrow \Delta E = Q$

Where ΔE = change in energy $= E_2 - E_1$ & $W = 0$

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Steady flow process

It is defined as the process during which all properties of fluid within the system remains constant w.r.t time.

Total energy of open & closed system

The total energy, $e = U + K.E + P.E$

$$\Rightarrow e = U + \frac{V^2}{2} + gZ \ \text{J/kg}$$

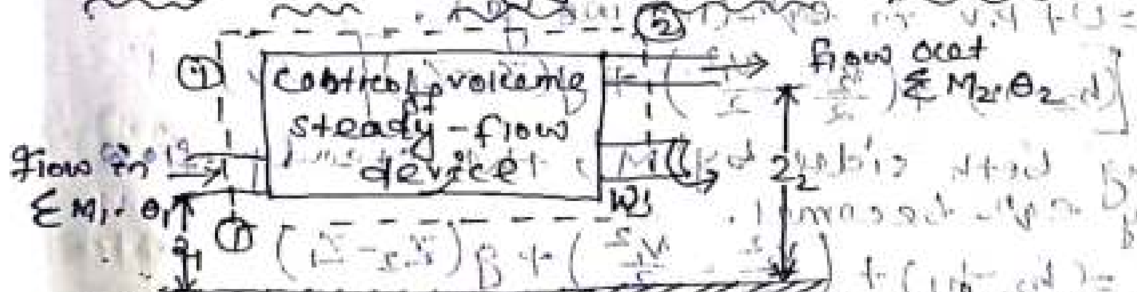
Potential, Kinetic	Potential, Kinetic
$e = U + \frac{V^2}{2} + gZ$ (Internal)	$\theta = U + PV + \frac{V^2}{2} + gZ$ (flow energy, Internal)
a. Total energy of a non-flow system.	b. Total energy of a flow system.

$$\theta = h + \frac{V^2}{2} + gZ$$

where, θ = Total energy of the flowing fluid on unit mass basis.

(h = enthalpy)

Steady flow energy balance equation



Consider a steady flow device with control volume.

Let Q = Rate of heat transfer to control volume in watt

W = Rate of shaft work in watt.

P = Pressure in N/m2

U = specific internal energy in J/kg

h = Specific enthalpy in J/kg

V = Velocity of fluid m/s

Z = Elevation above datum in m

θ = Total energy of fluid in J/kg.

ΣM_1 = Total mass flow rate in kg/s into the control volume.

ΣM_2 = Total mass flow rate out of the control volume (in kg/s)

- The energy balance on the control volume is the total energy crossing the boundary as heat & work.

The total energy leaving the control surface = The total energy entering into the control surface =

$$Q - W = \Sigma M_2\theta_2 - \Sigma M_1\theta_1 \quad \text{——(i)}$$

For a single flow system (one inlet & one exist), the eqn-(i) becomes -

$$Q - W = \Sigma M_2\theta_2 - \Sigma M_1\theta_1 \quad \text{——(ii)}$$

where M_1 = Mass flow rate at inlet

M_2 = Mass flow rate at exist

We know the total energy,

$$\theta = U + P.V + \frac{V^2}{2} + gZ \quad \text{——(iii)}$$

U = Internal energy, gZ = potential energy

PV = Flow energy, $V^2/2$ = kinetic energy.

Putting the value of 'θ' in eqn-(ii), we get,

$$Q - W = \Sigma M_2\left(U_2 + P_2V_2 + \frac{V_2^2}{2} + gZ_2\right) - \Sigma M_1\left(U_1 + P_1V_1 + \frac{V_1^2}{2} + gZ_1\right)$$

For steady flow energy balance, the mass flow rate entire the control volume remains constant.

i.e. $M_1 = M_2 = M$

So the above eqn. becomes

$$Q - W = M\left[(U_2 - U_1) + (P_2V_2 - P_1V_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1)\right] \quad \text{——(iv)}$$

Using $h = U + P.V$ in eqn-(iv), we get.

$$Q - W = M\left[(h_2 - h_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1)\right] \quad \text{——(v)}$$

Dividing both sides by M, the steady flow energy eqn becomes.

$$q - w = (h_2 - h_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1)$$

$$\Rightarrow q - w = \Delta h + \Delta K.E + \Delta P.E$$

where $q = \frac{Q}{M}$ = heat transfer per unit mass in J/kg

$w = \frac{W}{m}$ = Work transfer per unit mass in J/kg

The above eqn can be written as

$$\boxed{q - w = \Delta U + \Delta P.V + \Delta K.E + \Delta P.E} \; J/kg.$$

Steady flow device

1. Turbine 2. Compressor

1. Turbine:-

It is a device which takes water from a height & it's potential energy converted into kinetic energy & now used to generate electric power (shaft work), which is

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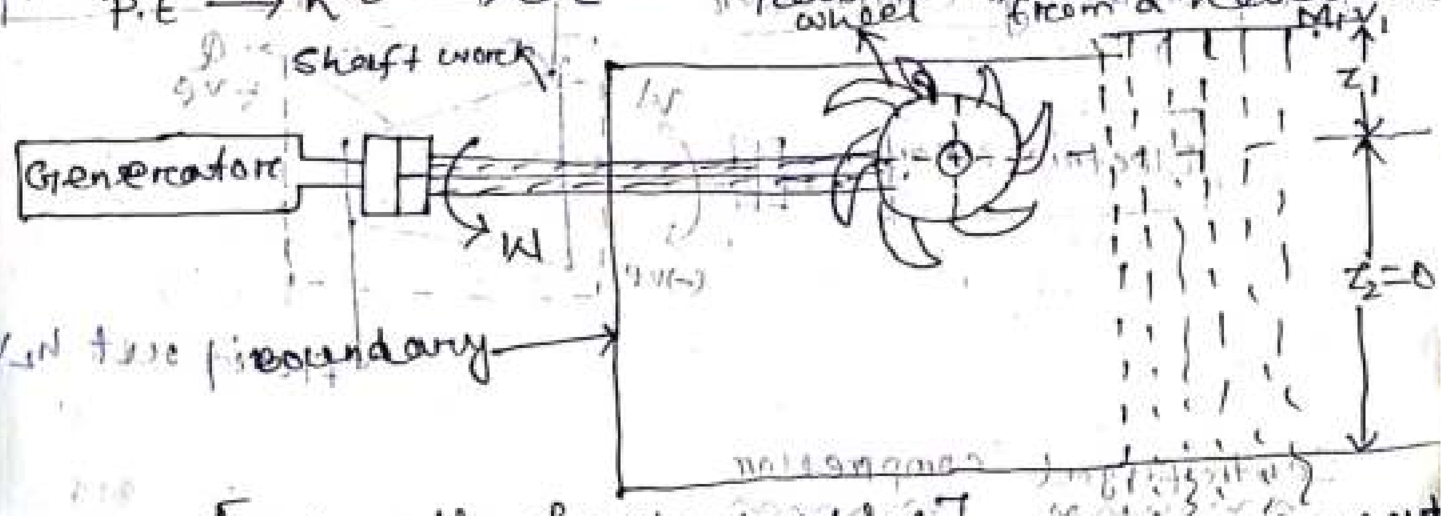
P.E → K.E → E.E



[Schematic of water turbine]

Rate of work by turbine = W = (+)ve
heat transfer from turbine, Q = 0
ΔU = change in specific internal energy = 0
The steady flow energy eqn reduces.

$$q - w = \Delta U + \Delta PV + \Delta K.E + \Delta P.E.$$

$$Q - W = M_1(U_1 - U_2) + (P_2V_2 - P_1V_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1)$$

$$\Rightarrow 0 - W = M\left[0 + (P_2V_2 - P_1V_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1)\right]$$

$$\Rightarrow \boxed{M\ (P_2V_2 - P_1V_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right) + g(Z_2 - Z_1) + W = 0}$$

2. <u>Compressor</u>

It is a device which takes air in low pressure & compresses it to a high pressure.

(i) <u>Reciprocating compressor</u> – In this compressor rate of work input = –ve
heat rejection = +ve
ΔP.E = 0
ΔK.E = 0

So the steady flow energy equation becomes

$$\boxed{Q - W = M(h_2 - h_1)\ J/s}$$

$$= M\left[(U_2 - U_1) + (P_2V_2 - P_1V_1)\right]\ J/s.$$

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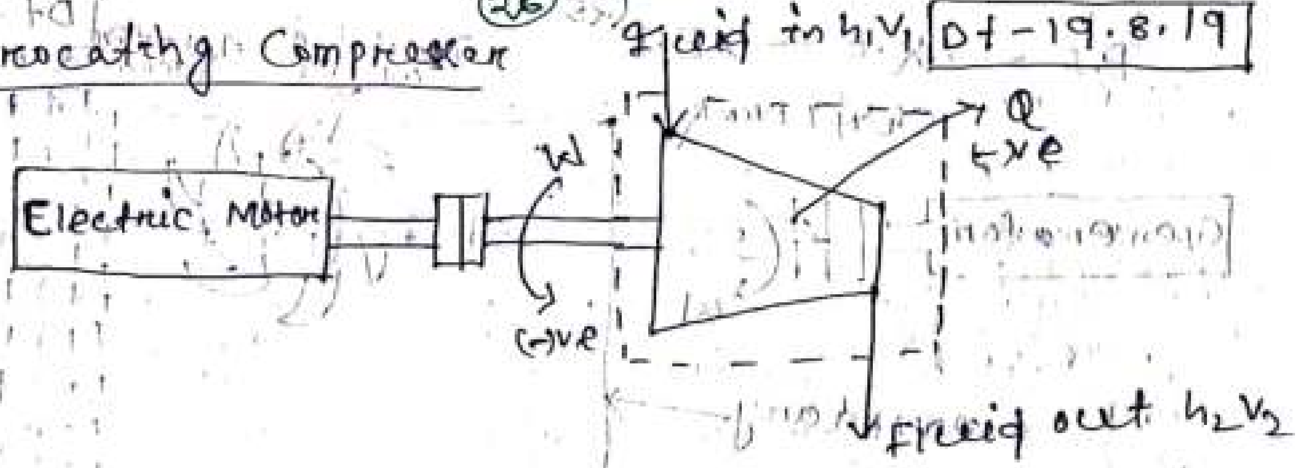
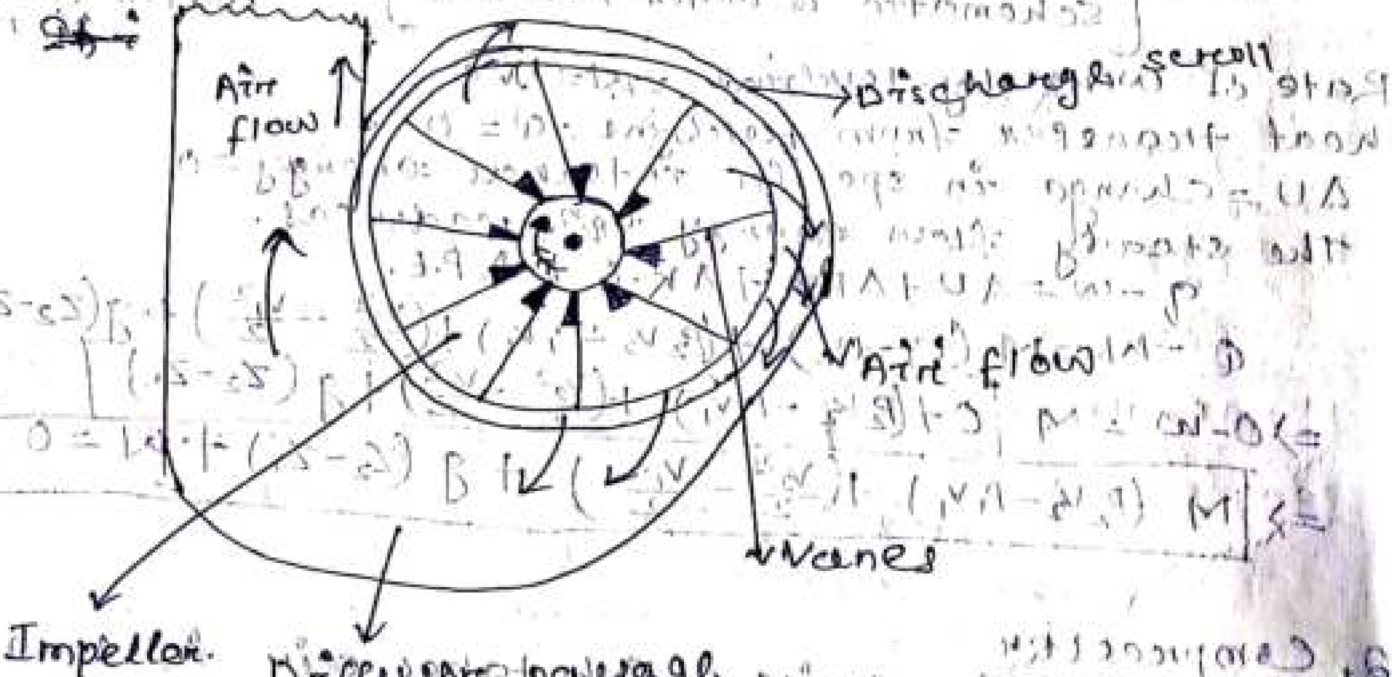
Reciprocating Compressor



Centrifugal compressor



In this compressor; the change in potential energy = 0.

Work input = (-)ve

Rate of heat transfer (Q) = (-)ve

The steady flow energy equation becomes.

$$Q - W = m\left[(h_2 - h_1) + \left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right)\right]$$

Q. Steam enter a turbine with a velocity of 40 m/s and specific enthalpy of 2500 kJ/kg; and leaves with a velocity of 90 m/s & specific enthalpy of 2030 kJ/kg. Heat losses from the turbine to the surrounding are 240 kJ/min & the steam flow rate is 5040 kg/h. Neglect the change of potential energy. Find the power developed by the turbine.

Soln. Given data

$v_1 = 40\ m/s$, $v_2 = 90\ m/s$

enthalpy $h_1 = 2500\ kJ/kg$

" $h_2 = 2030\ kJ/kg$

$Q = 240\ kJ/min = \frac{240}{60} = 4\ kW$ [$1\ kW = 60\ kJ/min$]

mass '$\dot{m}$' $= 5040\ kg/h$

$= \frac{5040}{3600} = 1.4\ kg/sec$

$$Q - W = m\left[(h_2 - h_1) + \left(\frac{v_2^2}{2} - \frac{v_1^2}{2}\right)\right]$$

$$\Rightarrow -4 - W = 1.4\left[(2030 - 2500) + \left[\frac{(90)^2}{2} - \frac{(40)^2}{2}\right]\right]$$

~~$\Rightarrow -4 - W = 2592$~~

~~$\Rightarrow W = -4 - 2592 = -2596$~~

~~$\Rightarrow -4 - W = 1.4\ (-470 + 3250) = 1.4 \times 2780 = 3892$~~

~~$\Rightarrow W = -4 - 3892 = -3896$~~

$\Rightarrow -4 - W = 1.4\ (-470 + 3.250)$ [$\because K.E = 3250\ J/kg = 3.250\ kJ/kg$]

$\Rightarrow W = 649.45\ kW = P$

-466.75

-658 -470 3250 2780 3892 2856

Q. Air at 100 kPa & 280 K is compressed steadily to 600 kPa & 400 K. The mass flow rate of air is 0.02 kg/s & heat losses of 16 kJ/kg occurs during the process. Assuming the change in potential & kinetic energies are negligible, determine the necessary power input to the compressor.

Sol^n: Given data:

$P_1 = 100$ kPa, $P_2 = 600$ kPa

$T_1 = 280$ K, $T_2 = 400$ K.Pa

$\dot{m} = 0.02$ kg/s

$q = \frac{Q}{\dot{m}} = -16$ kJ/kg

$P = \dot{m} w$

$w = \frac{W}{\dot{m}}$, $q = \frac{Q}{\dot{m}}$

$q - w = \Delta h + \Delta PE + \Delta KE$

$\Rightarrow \Delta h = C_p (T_2 - T_1)$ $\because C_p = 1.005$ kJ/kgK

$\Delta h = 1.005 (400 - 280)$

$= 1.005 \times 120 = 120.6$ kJ/kg.

Then $-16 - w = 120.6$

$\Rightarrow w = -16 - 120.6$

$= -136.6$ kJ/kg

$P = 0.02 \times (-136.6) = -2.732$ kW.

Limitation of 1st law of Thermodynamics :-

(i) During this cyclic process, the net work transfer is always directly proportional to the heat transfer, So in this process it is doesn't impose any restriction on direction in which the process occurs.

(ii) All heat transfer to a heat engine converted into usefull work which is not possible.

Ex:- ① In an electric work, it is converted into heat energy through an electric heating element.

② If a glass of hot milk is left in a room, then it gradually cools & the heat is rejected but in reversed process it is not possible to heat the milk in that room.

Dt - 21.8.19

Second law of thermodynamics

V.V.I

Clausius statement :-

It is stated that, "it is impossible for any ~~const~~ device that operates in a cycle, the heat energy can not be transfer from a low temperature to a high temperature body without addition of external work.

Kelvin Plank statement :-

It is stated that "it is impossible to construct an engine which while operating in a cycle, the engine can not convert all heat into work, while exchanging heat from a single temperature reservoir.

This engine receives heat from a high temp. reservoir and rejects heat to a low temp. reservoir.

Reservoir :- It supplies heat energy is called heat source.

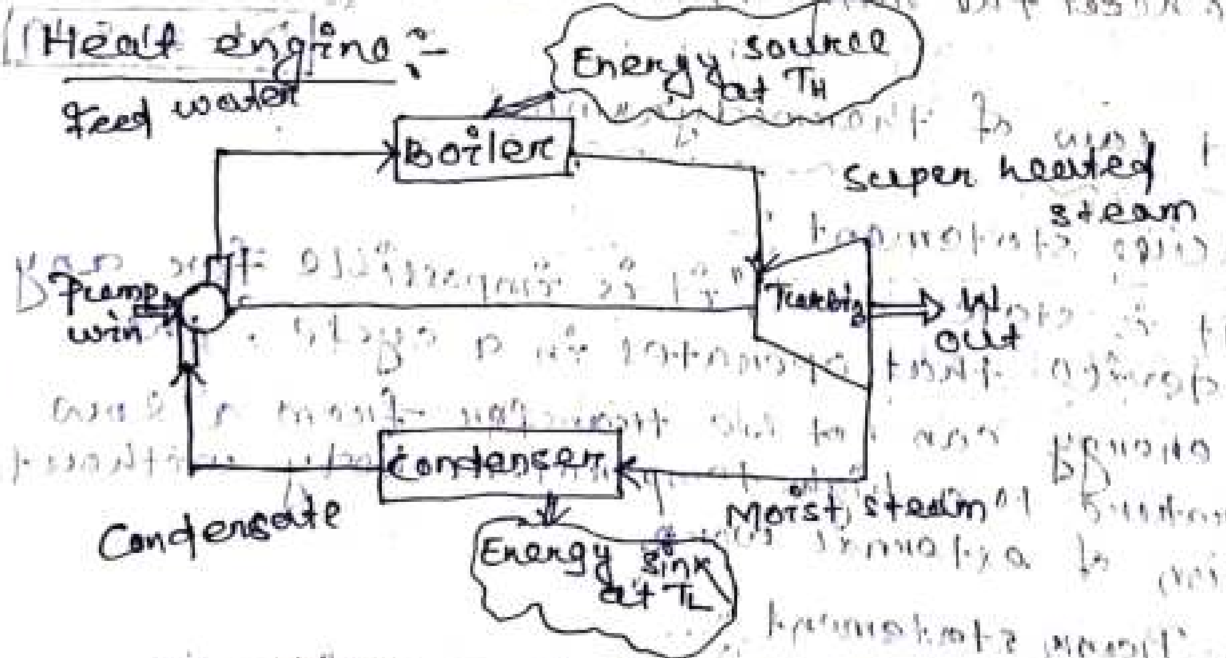
It absorbs heat is called heat sink.

Thermal Reservoir :-

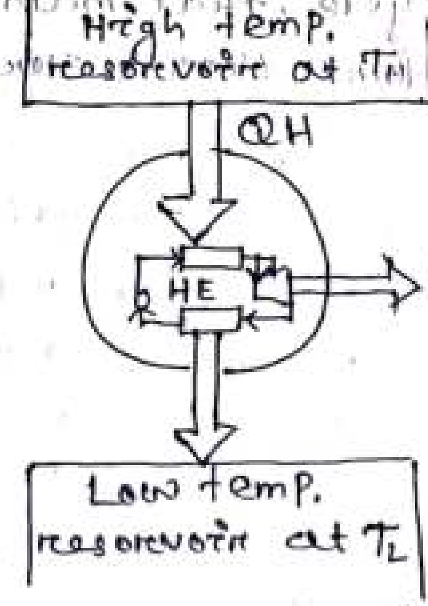
It is a hypothetical body with an ~~intensity~~ infinite amount of heat and it supply and absorb any amount of heat without affecting its temperature.

Application of 2nd law of thermodynamics

Heat engine :-



(a) schematic diagram of a steam power plant



(b) schematic diagram of heat engine

Dt-22.8.19

$$\boxed{W_{net} = Q_H - Q_L}$$

Q_H → Heat supply (source)
Q_L → Heat rejected (sink)

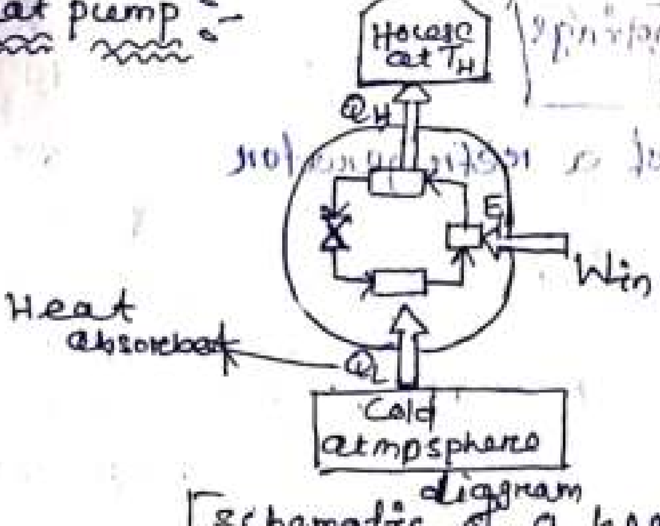
η_{th} heat engine $= \frac{W_{net}}{Q_H}$

$$\boxed{\eta_{th} \text{ heat engine} = \frac{Q_H - Q_L}{Q_H}}$$

Heat engine :-

It is a device which operates in a cycle and it is receives the heat energy from a high temperature reasorevoir, converts some of heat into work and rejects remaining heat to the low-temperature reasorevoir.

Heat pump :-



[schematic diagram of a heat pump]

→ It is a device operating a cycle, that maintains a space (room) higher temperature than a surrounding.

$$COP_{HP} = \frac{\text{Heat supplied}}{\text{Work input}}$$

COP → Co-efficient of performance

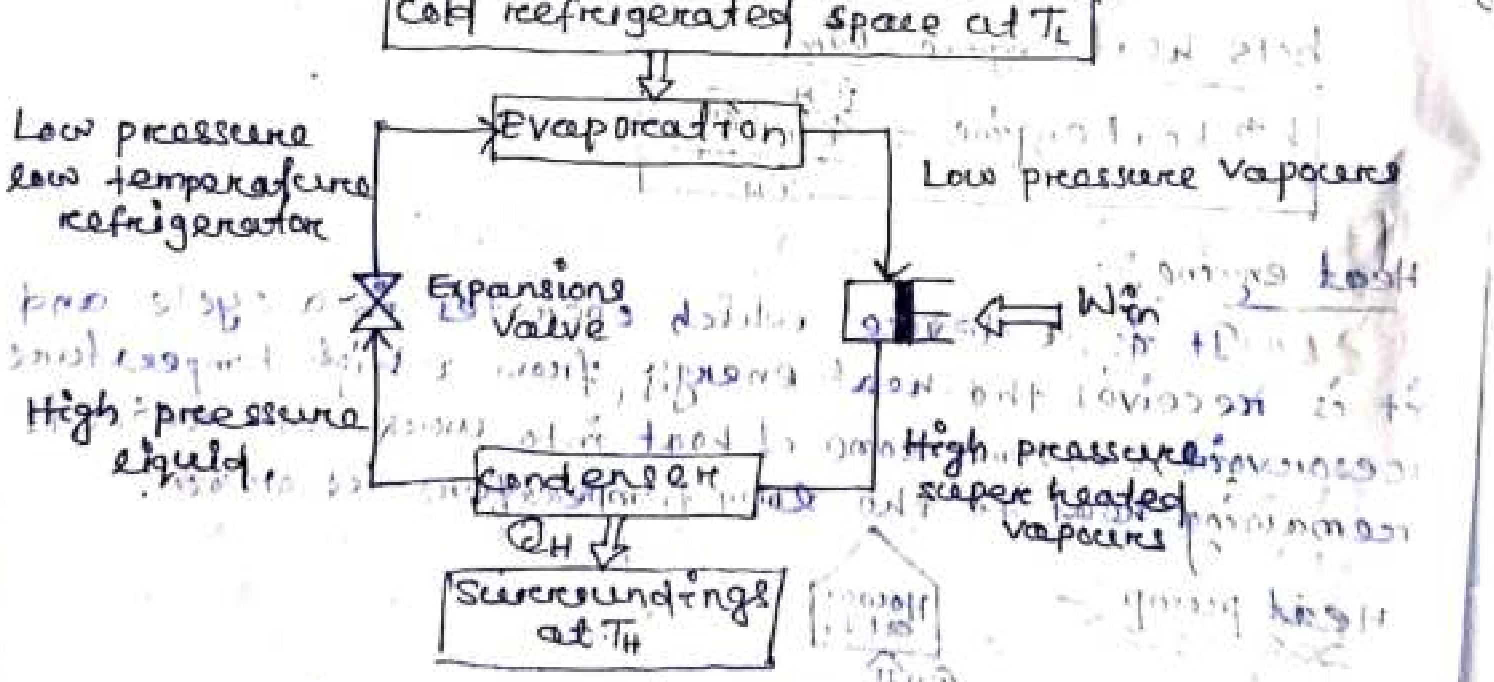
$$= \frac{Q_L + W_{in}}{W_{in}}$$

$$\boxed{COP_{HP} = \frac{Q_L}{W_{in}} + 1}$$

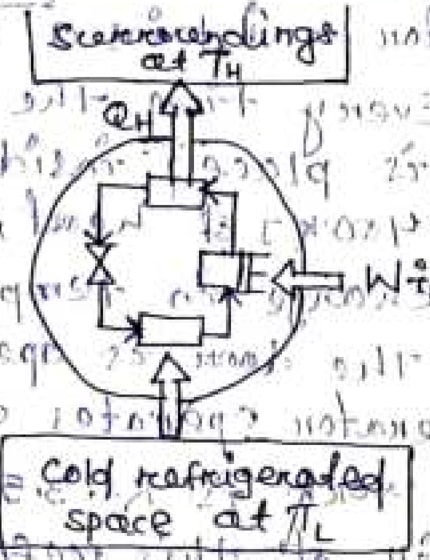
$$\boxed{= COP_R + 1}$$

Refrigerator :-

It is a device operating in a cycle, that maintains a body lower temperature that a surroundings.



(a) Basic component of a refrigerator



(b) schematic diagram of a refrigerator

$$(COP)_R = \frac{\text{Refrigerating effect}}{\text{Work input}} = \frac{Q_L}{W_{in}}$$

$$(COP)_R = \frac{Q_L}{Q_H - Q_L}$$

Q.1 A heat engine operates on a Carnot cycle between source and sink temperature of 337°C and 57°C respectively. If the heat engine receives 400 kJ of heat from source find the efficiency, net work done and heat rejected to the sink.

Soln. Given data $T_H = 337°C = 337+273 = 610\,K$

$T_L = 57°C = 57+273 = 330\,K$

$Q_H = 400\,kJ$

$$\eta_{rev} = 1 - \frac{T_L}{T_H}$$

$$\Rightarrow \eta_{rev} = 1 - \frac{330}{610} = 0.45 = 45\%$$

$$\eta_{th} = \frac{W_{net}}{Q_H} \Rightarrow 0.45 = \frac{W_{net}}{400}$$

$$\Rightarrow W_{net} = 0.45 \times 400 = 180\,kJ$$

$$W_{net} = Q_H - Q_L$$

$$\Rightarrow Q_L = Q_H - W_{net} = 400 - 180 = 220\,kJ$$

Q.2 A household refrigerator maintains a space at a temperature of 0°C. Every time the door is opened warm material is placed inside introducing an avarge 400 KJ of heat, about making only a small change in temperature of the refrigerator. The door is opened 25 times a day and the refrigerator operates at 25% of ideal cop. The cost of work is Rs. 3.50 per KWh. What is the monthly bill of this refrigerator? The atmospheric temperature is at 30°C.

Sol^n. Given data

$T_H = 30°C + 273 = 303 K$

$T_L = 0°C + 273°C = 273 K$

$Q_L = 400 KJ$

$= 400 \times 25 \times 30$

$= 300000 KJ.$

$COP_{(Act)} = 0.25 \times COP_{(Ideal)}$

$$COP_{(Ideal)} = \frac{T_L}{T_H - T_L} = \frac{273}{303 - 273} = 9.1$$

$COP_{(Act)} = 0.25 \times 9.1 = 2.275$

$$COP_{(R)} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{(R)} = \frac{Q_L}{W_{in}}$$

$$\Rightarrow 2.275 = \frac{300000}{W_{in}}$$

$$\Rightarrow W_{in} = \frac{300000}{2.275} = 131868.13 KJ$$

~~power~~ 1 Electric unit = 1 KWh = 3600 KJ

power consume per unit $= \frac{131868.13}{3600} = 36.63$ KWh

Total Monthly bill $= 36.63 \times 3.50 = 128.20$

CH-3 Properties Process of Perfect gas

Dt-26-8-19

Ideal gas :-

Ideal gas Model :- A gas can be modeled as ideal gas when it has the following features:-

1. It has no molecular forces of attraction or repulsion.
2. It does not change its phase during a thermodynamic process.
3. It obeys Boyle's law, Charle's law and characteristic gas constant

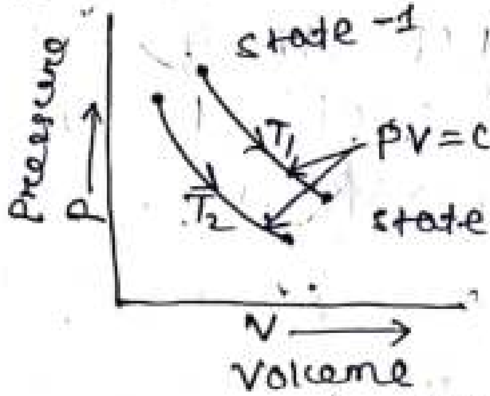
At zero pressure all real gases behave as ideal manner, that state is called ideal state

Boyle's law :-

It states that when a gas undergoes a process at constant temperature its specific volume is inversely proportional to absolute pressure

$v \propto \frac{1}{P}$ (T= Constant)

$\Rightarrow \boxed{PV = C}$



If a gas changes in state from P_1V_1 to P_2V_2 without change in temperature then

$P_1V_1 = C$

$P_2V_2 = C$

so, $P_1 V_1 = P_2 V_2$

this curve is called isotherm and the process at constant temperature is called isothermal process.

Mayer's equation / Relationship betn C_p & C_v

C → specific heat (S.H.)

C_p → S.H. at constant pressure (kJ/kgK)

C_v → S.H. at volume

R → characteristic gas constant

5 law of perfect gas

1. Boyle's law → (T = constant) → $P \propto \frac{1}{volume}$

$\Rightarrow \frac{PV}{T} = \text{constant}.$

$\Rightarrow PV = \text{constant}$

$PV = mRT$ (R → 0.287 kJ/kgK)

1 mole

1 mole = 6.023×10^{23} amu

$m = \frac{\text{universal gas constant}}{\text{characteristic gas const.}} = \frac{R_u}{R}$

2. Charl's law (P = constant) → Isobaric

$V \propto T$, $\Rightarrow \frac{V}{T} = C$ → constant.

3. Gay-Lussac law (V = constant) → Isochoric

$\frac{PV}{T}$ → $\frac{P}{T} = C$

$\frac{C_p}{C_v} = \gamma$ → 1.4 for air medium

(→ Isentropic expansion / index)

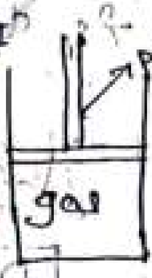
Belsen 26.08.19

Dt - 27.8.19

5 Mark

$C_p - C_v = R$ → Mayers equation

Case-I



At constant volume

$Q = mC_v\Delta T = C_v\Delta T$ (∵ m = 1 mole) —— (i)

Work done = Force × displacement

$W = P \times V$

$W = Pdv$ → flow process

$W = P \times 0 = 0$ (at, V = constant) —— (ii)

According to 1st law of Thermodynamics

$\Rightarrow Q = \Delta U + W$

$\Rightarrow C_v\Delta T = \Delta U + 0$

$\Rightarrow \Delta U = C_v\Delta T$

Case-II

At constant pressure

$Q = mC_p\Delta T = C_p\Delta T$ (∵ m = 1 mole) —— (i)

$W = Pdv$

$dQ = \Delta U + W$

$\Rightarrow dQ = C_v\Delta T + Pdv$

$\Rightarrow C_p\Delta T = C_v\Delta T + Pdv$ → (iii)

According to gas equation

$PV = mRT \Rightarrow PV = RT$ → at constant pressure

$\Rightarrow Pdv + vdp = RdT$ (vdp → 0)

$\Rightarrow Pdv = R\Delta T$ —— (iv)

Put the value of Pdv in eqn — (iii)

$C_p\Delta T = C_v\Delta T + R\Delta T$

$\Rightarrow C_p - C_v = R$ (Proved)

Dt - 28.8.19

Charl's law :-

It states that if a gas undergoes a process at constant pressure, the change in its specific volume is directly proportional to its absolute temperature change.

i.e. $V \propto T$

$$\Rightarrow \boxed{\frac{V}{T} = C}$$

where, C = constant of proportionality at constant (pressure)

For an Ideal gas undergoes a constant pressure from V_1T_1 to V_2T_2.

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$

Gaylussac's law :-

It states that the absolute pressure of an ideal gas varies directly with absolute temperature, at constant volume.

i.e. $P \propto T$

$$\Rightarrow \boxed{\frac{P}{T} = C}$$

where, C = Constant of proportionality at constant volume.

For an Ideal gas undergoes a constant volume from P_1T_1 to P_2T_2

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

Avogadro's law :-

It states that the molecular mass of all perfect gases occupies the same volume under identical conditions of pressure and temperature.

This experiment shows that the average volume of 1 kmole for any perfect gas i.e. 22.413 m^3/kmol at standard atmospheric pressure (1.013 bar) and 0°c (N.T.P condition)

$$V = \frac{mRT}{P} = \frac{R_u T}{P} = \frac{8.314\ kJ/kmol \times 273.15}{101.325\ kPa}$$

$$= \boxed{22.413\ m^3/kmol}$$

Dalton's law of partial pressure :-

It states that the sum of partial pressure of the constituents in a gas mixture is equal to the total pressure of the mixture.

The partial pressure P_i of i^{th} component in a gas mixture, alone at temperature (T) & volume (V).

$$\boxed{P_i = \frac{n_i R_u T}{V}} \quad \text{--- (1)}$$

Using ideal gas equation

$V = \frac{n R_u T}{P}$ in eqn-(1), we get

$$P_i = \frac{n_i R_u T}{n R_u T} \times P$$

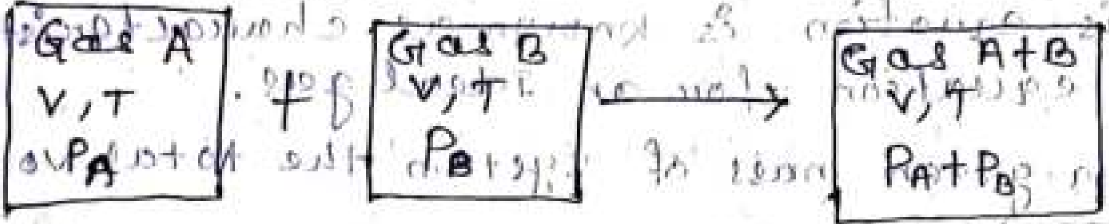
$$\Rightarrow P_i = \frac{n_i}{n} \times P$$

The total pressure of the mixture is

$$P = \frac{(n_1 + n_2 + n_3 + \dots + n_k) R_u T}{V}$$

So, $P = P_1 + P_2 + P_3 + \dots + P_k$

$= \Sigma P_i$



Dt-29.8.19

Equation of state :-

[Any equation that relates the pressure, temperature and specific volume of a substance is known as equation of state.

i.e. $F(P, V, T) = 0$

(i.e) $P = f(V, T)$; $V = g(P, T)$, $T = h(P, V)$

↳ constant

Characteristics of gas constant (R)

If any thermodynamics system of an Ideal gas, the pressure, temperature and specific volume vary simultaneously. This characteristic gas equation is derived from Boyle's law and Charle's law.

From the combination of both relation we get,

$$v \propto \frac{T}{P}$$

$$\left[\begin{array}{l} v \propto \frac{1}{P} \text{ at } T = C \\ v \propto T \text{ at } P = C \end{array}\right]$$

$\Rightarrow$ $\boxed{PV = RT}$

where, R = specific gas constant (or) characteristic gas constant.

P = Absolute pressure

V = specific volume

T = Absolute temperature.

This equation is known as characteristic gas equation for an Ideal gas.

For a given mass of system the total volume

$V = mv$ (m^3)

then $PV = mRT$

where $m = nM$ (kg) [∵ n = no. of kmols]

M = Molecular mass in kg/mol

Universal gas constant :- (R_u)

When the molecular mass of any gas (M) is multiplied by its specific gas constant (R) then the product (MR) is always small for all gases.

So, $R_u = MR$

For S.I system $R_u = 8.314$ KJ/Kmol K

Characteristic gas constant (R)

It is the specific gas constant, its value is different for different gases.

$$R = \frac{R_u}{M}$$

where, R_u = Universal gas constant,

M = Molecular mass

Unit of R = KJ/kgK

Change of state of an Ideal gas

The ideal gas equation $PV = mRT$ for an Ideal gas undergoing change of state from $P_1V_1T_1$ to $(P_2V_2T_2)$.

at the state 1 = $P_1V_1 = mRT_1$

$$\Rightarrow \frac{P_1V_1}{T_1} = mR \quad (1)$$

at state 2 = $P_2V_2 = mRT_2$

$$\Rightarrow \frac{P_2V_2}{T_2} = mR \quad (2)$$

Equating the both eqn. we get,

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}} = C$$

It is a property relation for an Ideal gas.

Non-Flow process

A process in which the mass of the system doesn't change is called non flow process.

1. Isothermal process (constant temp. process)
2. Isobaric process (constant pressure process)
3. Isochoric pressure (constant volume)
4. Isentropic process (constant Entropy process)
5. polytropic process (In general)

1. Isothermal process

Law $T = C$ or $PV = C$

$P_1V_1 = P_2V_2$

Work transfer, $W = P_1V_1 \ln(V_2/V_1)$

$= mRT \ln(P_1/P_2)$

Heat transfer, $Q = W$

change in entropy $\Delta s = mR\ln(V_2/V_1)$

$= mR\ln(P_1/P_2)$

2. Constant pressure process (Isobaric)

Law $P = C$, and $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Work transfer, $W = P(V_2 - V_1)$

Heat transfer, $Q = mC_p(T_2 - T_1) = \Delta H$

Change in entropy $\Delta S = mC_p\ln(T_2/T_1)$

3. Constant-volume process (Isochoric)

Law $V = C$, $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Work transfer, $W = 0$

Heat transfer $Q = mC_v(T_2 - T_1) = \Delta U$

change in entropy $\Delta S = mC_v\ln(T_2/T_1)$

Change in enthalpy $\Delta H = mC_p(T_2 - T_1)$

4. Isentropic process

Law $PV^\gamma = C$

$\Rightarrow \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{1-\gamma} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

Work transfer $W_{1-2} = \frac{P_2V_2 - P_1V_1}{1-\gamma} = \frac{mR(T_2 - T_1)}{1-\gamma} = \Delta U$

Heat transfer $Q = 0$

Change in entropy $\Delta S = 0$

5. Polytropic process

Law $PV^n = C$

Properties relation $\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{1-n} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

Work transfer, $W = \frac{P_2V_2}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$

Heat transfer $Q = mC_n(T_2 - T_1)$

where polytropic specific heat $C_n = \frac{C_p - nC_v}{1-n}$

change in entropy, $\Delta s = m C_v \ln\left(\frac{T_2}{T_1}\right)$

Dt-4.9.19

Q. A certain gas occupies a volume of $0.3 m^3$ at a pressure of 2 bar. The temp. of the gas at this state is 350 K. The gas undergoes a thermodynamic constant-volume process until the pressure raises to 7 bar. Determine the temp. at the end of the process, change in internal energy, change in enthalpy and change in entropy during this process. Take $C_v = 0.712$ kJ/kg·K & $R = 0.287$ kJ/kg·K.

Soln: Given data

$V = 0.3 m^3$

$P_1 = 2$ bar $= 200$ kP, $P_2 = 7$ bar $= 700$ kP

$T_1 = 350$ K

$C_v = 0.712$ kJ/kg K

$R = 0.287$ kJ/kg·K

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow \frac{200}{350} = \frac{700}{T_2}$$

$$\Rightarrow T_2 = \frac{700 \times 350}{200} = 1225 K.$$

$PV = mRT$

$$\Rightarrow m = \frac{PV}{RT} = \frac{200 \times 0.3}{0.287 \times 350} = 0.597$$

change in Internal energy $\Delta U = m C_v (T_2 - T_1)$

$= 0.595 \times 0.712 (1225 - 350)$

$= 370.685$ kJ.

change in enthalpy $\Delta H = m C_p (T_2 - T_1) = 0.597 \times 0.999 (1225 - 350)$

$= 521.85$ kJ/kg K.

$C_p - C_v = R \Rightarrow C_p = R + C_v = 0.287 + 0.712 = 0.999$

(46)

Chang in entropy $\Delta S = m C_v \ln(T_2/T_1)$

$= 0.597 \times 0.712 \left(\ln \frac{1225}{350}\right)$

$= 0.23$

Throttling Process [2 mark]

(i) It is an irreversible.

(ii) When a fluid expands from high pressure to low pressure through a open valve or capilary tube without exchanging the heat energy and work transfer then the enthalpy of the fluid remains constant. This fluid is called undergo throttling process.

Dt- 10.9.2019

Isothermal Process

When an Ideal gas of mass 'M' undergoes a reversible Isothermal process from state 1 to 2, the work done is

$$\int_1^2 dw = \int_{V_1}^{V_2} P\,dV$$

$$\Rightarrow W_{1-2} = \int_{V_1}^{V_2} \frac{mRT}{V} dv \quad \left[\because PV = mRT \Rightarrow P = \frac{mRT}{V}\right]$$

$$= mRT \ln \frac{V_2}{V_1}$$

$$= mRT \ln \frac{P_1}{P_2}$$

The heat transfer involved in process

$$Q_{1-2} = W_{1-2} = mRT \ln\left(\frac{V_2}{V_1}\right) = T(S_2 - S_1)$$

Polytropic Process:

In this process $PV^n = \text{constant}$, where n is constant and it depends on the process.

For two states on the process

$$P_1 V_1^n = P_2 V_2^n$$

$$\Rightarrow \left(\frac{V_2}{V_1}\right)^n = \frac{P_1}{P_2} \Rightarrow n = \frac{\log P_1 - \log P_2}{\log V_2 - \log V_1}$$

The two other relation of a polytropic process is:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

Consider a unit mass of an Ideal gas

so, $Q - W = u_2 - u_1$

$$= C_v(T_2 - T_1)$$

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

$$= \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

$$= \frac{P_1V_1}{\gamma - 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{P_1V_1}{\gamma - 1}\left[\left(\frac{V_1}{V_2}\right)^{n-1} - 1\right]$$

Dt - 11.9.19

Isentropic Process (Constant Entropy process)

When an adiabatic (no exchange of heat between system and surroundings) is reversible (frictionless), then this process is called Isentropic process.

For an unit mass of a system, then the energy equation for a non-flow process is

$$\delta q = du + \delta w$$

For an adiabatic process $\delta q = 0$

$$\therefore du + \delta w = 0$$

$$\Rightarrow C_v dT + P dv = 0 \quad \text{---} (1)$$

For an unit mass of an Ideal gas, the eqn is

$$Pv = RT$$

Differentiating both sides we get.

$$P dv + v dP = R dT \quad \text{---} (2)$$

$$\Rightarrow dT = \frac{P dv + v dP}{R}$$

Substituting the value of dT in eqn (1) we get.

$$C_v \left(\frac{P dv + v dP}{R} \right) + P dv = 0$$

$$\Rightarrow \frac{C_v P dv + C_v v dP + R P dv}{R} = 0$$

$$\Rightarrow C_v P dv + C_v v dP + R P dv = 0$$

$$\Rightarrow C_v P dv + C_v v dP + (C_p - C_v)(P dv) = 0$$

$$\Rightarrow C_v P dv + C_v v dP + C_p P dv - C_v P dv = 0$$

Dividing both sides by $P v C_v$

$$\Rightarrow \frac{C_v v dP}{P v C_v} + \frac{C_p P dv}{P v C_v} = 0$$

$$\Rightarrow \frac{dP}{P} + \frac{C_p}{C_v} \frac{dv}{v} = 0 \Rightarrow \frac{dP}{P} + \gamma \frac{dv}{v} = 0$$

Integrating both the side

$$\int \frac{1}{p} dp + \gamma \int \frac{1}{v} dv = 0$$

$$\Rightarrow \ln p + \gamma \ln v = \ln C$$

where this term $\ln C$ is constant of integration.

Taking antilog on both the side we get.

$$pv^{\gamma} = C.$$

Q. A mass of 0.8 kg of air at 1 bar and 25°C is contain in a gas-tight frictionless piston cylinder device. The air is now compressed to a final pressure at 5 bar. During the process, the heat is transfered from air such that the temperature inside the cylinder remains constant. Calculate the heat transfered and workdone during the process and direction of each in the process.

Soln. Mass(m) = 0.8 kg

Press. P_1 = 1 bar = 100 kP, P_2 = 5 bar = 500 k.P.

Temp.(T_1) = 25°C + 273 = 298 K. ; $T_2 = T_1$

We know that, R = 0.287 kJ/kg.K (Gas constant)

C_v = 0.7165 kJ/kg.K

For isothermal compression process

$$W_{1-2} = mRT_1 \ln\left(\frac{P_1}{P_2}\right)$$

$$= 0.8 \times 0.287 \times 298 \times \ln\left(\frac{100}{500}\right)$$

$$= -110.12 \text{ kJ} \quad \text{(Ans)}$$

We know that $Q_{1-2} = W_{1-2} = -110.12$ kJ. (Ans)

CH-4 Interenal Combustion Engine

IC Engine:-

It is a machine that converts chemical energy in a fuel into a mechanical energy fuel is burnt in combustion chamber releases heat energy (chemical energy) which is converted into mechanical energy with help of reciprocating piston & crank mechanism.

Classification of IC engine

It has 2 types

1. Otto cycle (Petrol engine)
2. Diesel cycle (Diesel engine)

① According to the piston strokes in the working cycle

1. Two stroke
2. Four stroke

② According to the fuel used in working cycle

(i) Petrol engine.
(ii) Diesel engine,
(iii) Gas engine.
(iv) Multi fuel engine.

③ According to the method of ignition.

1. Spark ignition (SI) → Petrol engine
2. Compression ~~(---)~~ ignition (CI) → Diesel engine.

④ According to the feeding system

(i) Carburated engine (Petrol engine)
(ii) Fuel ~~engine~~ injection (Diesel engine)

⑤ According to the cooling system

(i) Air cooled
(ii) Water cooled

⑥ According to the number of cylinder.

1. Single cylinder
2. Multi cylinder.

(7) According to the speed of the engine
(i) Low speed
(ii) Medium speed
(iii) High speed

(8) According to the ~~piston~~ position of the engine
(i) Horizotanl
(ii) Vertical
(iii) V-engine

The 2 principle types of engine

1. Reciprocating
2. Rotating.

Terminology of IC engine

1. Bore(d) :- It is the internal diameter of the cylinder of reciprocating engine.
Unit - mm

2. Stroke(L) :- It is the linear distance through which the piston moves or travel between top dead centre (TDC) and bottom dead centre (BDC) in the cylinder.
Unit - mm

3. PEAP centre :- There are two fixed position in the cylinder between which the piston reciprocat
(i) TOP DEAD CENTRE.
(ii) BOTTOM DEAD CENTRE.

4. STROKE VOLUME (swept volume) :-
It is the volume ~~centred~~ created or displaced by the piston during one stroke travel.

$$V_s = \frac{\pi}{4} d^2 L$$

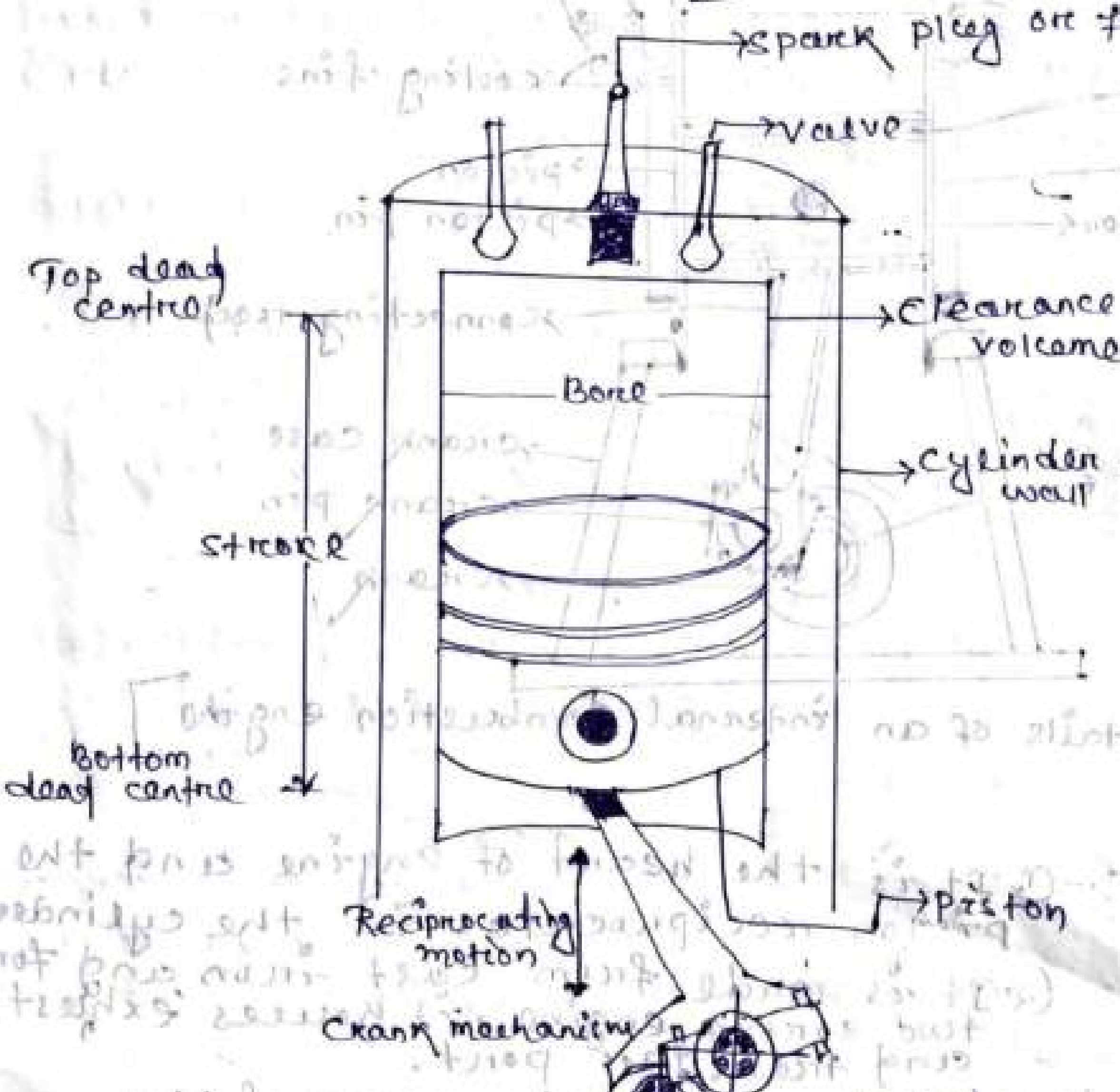
5. Piston speed :-

It is the linear distance travel by piston per second,

$$v = \frac{2LN}{60} \text{ m/s}$$

N → Engine speed (rpm)

[rpm → Revolution per minute]



[Nomenclature for reciprocating volume engine]

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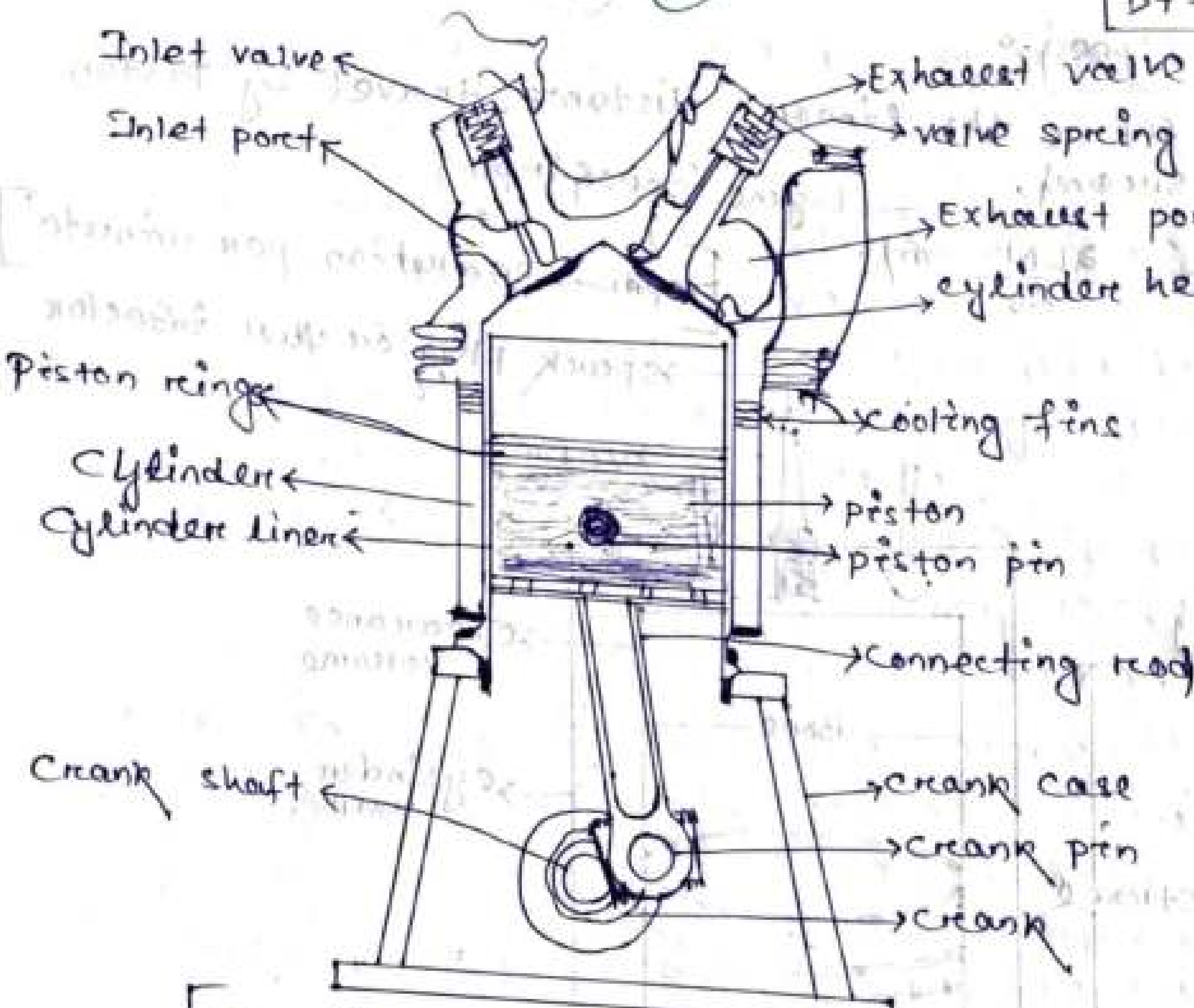

[Details of an internal combustion engine]

① Cylinder:- ① It is the heart of engine and the piston reciprocates in the cylinder.
② It is made from cast iron and for two stroke engine, it houses exhaust and transfer port.

② Cylinder head:- ① It is the top cover of the cylinder toward TDC.
② It houses spark plug in petrol engine and fuel injector in diesel engine.
③ In four stroke cycle, the cylinder head houses inlet and exhaust valves.

③ Piston :- ① It is the reciprocating member of the engine and it reciprocates in the cylinder.

② It is made from cast iron or aluminium.

④ Piston ring :- ① Two or three piston rings are provided on the piston.

② It is used to seal the space between cylinder liner and piston to prevent leakage.

⑤ Crank :- ① It is a rotating member and it makes ~~rotation~~ circular motion in the crank case.

② Its one end is connected to crank-shaft and other end is connected to the connecting rod.

⑥ Crank case :- ① It is the housing of crank and body of the engine to which the cylinder and other parts are fastened.

⑦ Connecting rod :- ① It is a link between piston and crank.

② It transmits power developed on the piston to the crank shaft.

⑧ Crank shaft :- ① It is the shaft, rotating member which connects the crank.

② The power developed by the engine is transmitted outside through the crank shaft.

⑨ Cooling fins :- ① It is provided to keep the engine parts with a safe temperature limit.

② It is provided with the cooling arrangement on light duty engines.

(10) Cam shaft :- (1) It is provided on four stroke engine.
(2) It carries two cams for controlling the opening & closing of inlet & exhaust valve.

(11) Inlet valve :- (1) This valve controls the admission of charge to the cylinder during suction stroke.

(12) Exhaust valve :- (1) The removal of exhausted gas after doing work on the piston by this valve.

(13) Inlet manifold :- (1) It is the passage ~~through~~ which carries charge/fuel from the carburator to the engine.

(14) Exhaust manifold :- (1) It is the passage which carries the exhaust gases from the exhaust valve to the atmosphere.

(15) Spark plug :-
It is provided on the petrol engine and it produces sparks (high intensity) which initiates the combustion process of charge/fuels.

(16) Fuel Injector :- It is provided on ~~petrol~~ diesel engine and the diesel fuel is injected in the cylinder at the end of compression under high pressure.

(17) Carburator :- It is provided with petrol engine and it prepares the mixture of the air & fuel.

(18) Fuel pump :- It is provided with a diesel engine and the diesel is taken from the fuel tank by fuel cup to the fuel injector.

(19). Fly wheel :- It is mounted on the crank shaft and it stores energy and also it minimizes the fluctuation of speed of the engine.

Imp

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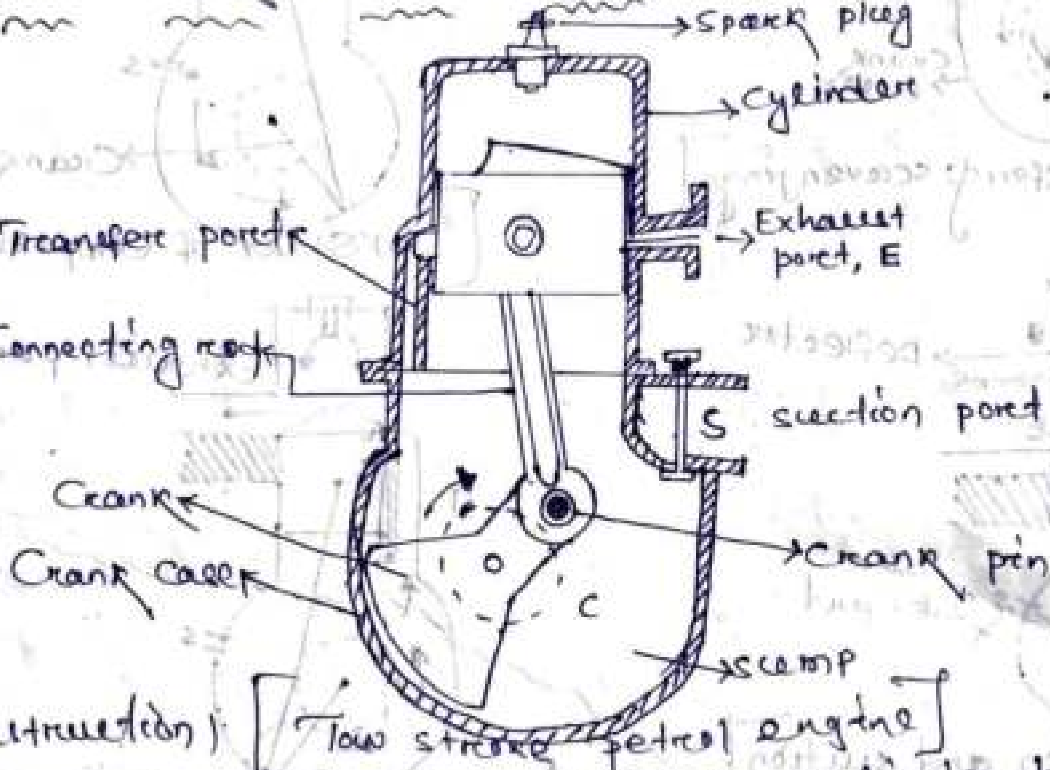
Two stroke Petrol engine



(construction) [Two stroke petrol engine]

→ It consists of cylinder, piston, cylinder head, piston ring, connecting rod, crank, crank case, crank shaft, etc.

→ The charge (air fuel mixture) is prepared outside the cylinder in the carburator.

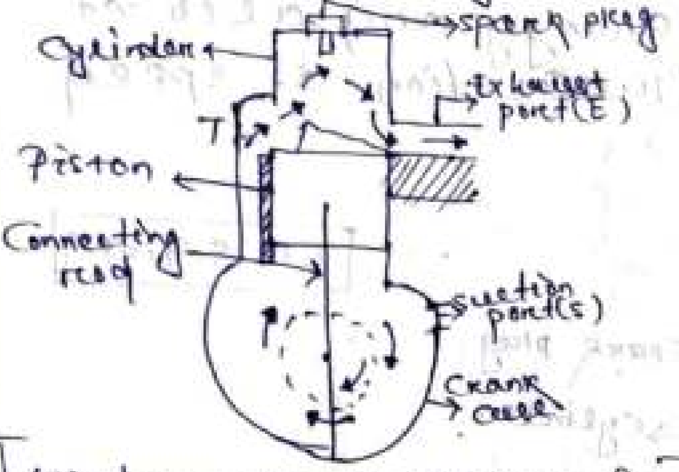
→ In two stroke engine the port are provided for inlet (charge) & exhaust (for removal of exhaust gas.).

→ The suction port (s) with reed type valve which is used for induction of charge into the crank case.

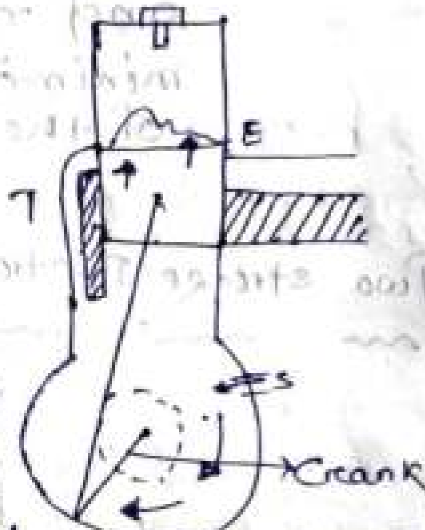
→ The transfer port (T) is used for transfer of charge from the crank case to the cylinder.

→ Exhaust port (E) is used for discharging the exhaust gases from the cylinder to the atmosphere.

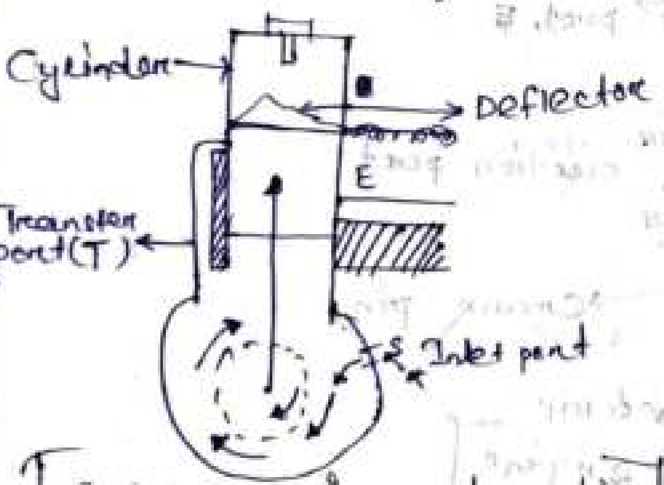
→ The spark plug is located in the cylinder head.



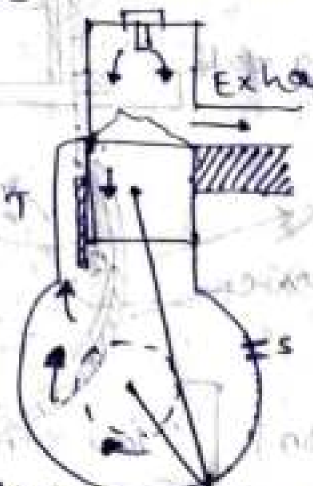
[(a) Charge transfer & scavenging]



[(b) Start of compression]



[(c) Compression and suction]



[(d) Power & exhaust]

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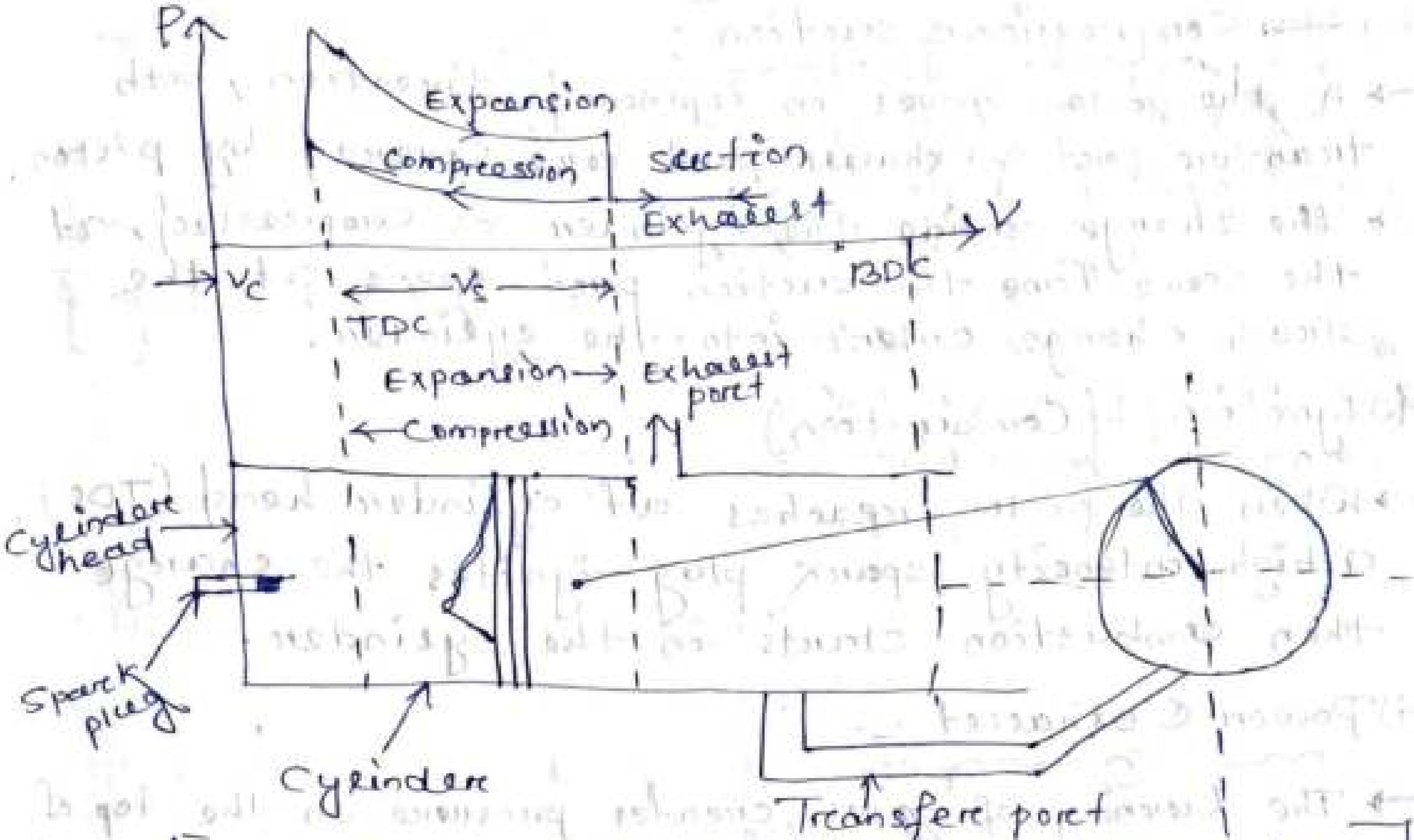


[PV Diagram & schematic of 2-stroke petrol engine]

(a) Charge transfer & scavenging

- → When the piston is near to the crank case (BDC) then the transfer port & exhaust port are uncovered.
- → The air fuel mixture (charge) is slightly compressed enters the transfer port & removes exhaust gases through exhaust port.
- → In this two stroke engine a deflector is used, so, the incoming charge is moved in upward direction & removes exhaust gases this operation is called scavenging.
- → As the piston moves upward, the fresh charge passage into the cylinder.

(b) ~~Star~~ Compression & suction :-

→ As the piston moves in upward direction, both transfer port & exhaust port are covered by piston.

→ The charge inside the cylinder is compressed, at the same time the suction port opens at the fresh charge enters into the cylinder.

(c) Ignition :- (Combustion)

→ When the piston reaches at cylinder head (TDC), a high intensity spark plug ignites the charge then combustion starts in the cylinder.

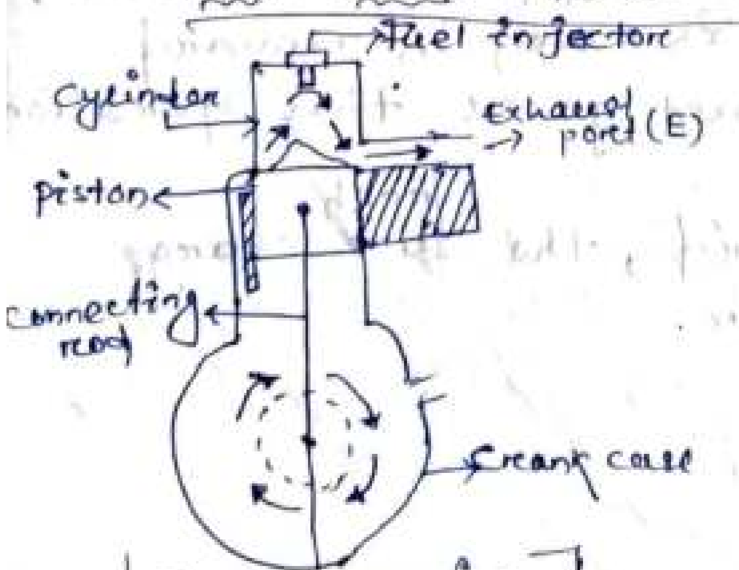
(d) Power & exhaust :-

→ The burning of gases creates pressure on the top of the piston, the piston is forced downward & generate pressure in the cylinder.

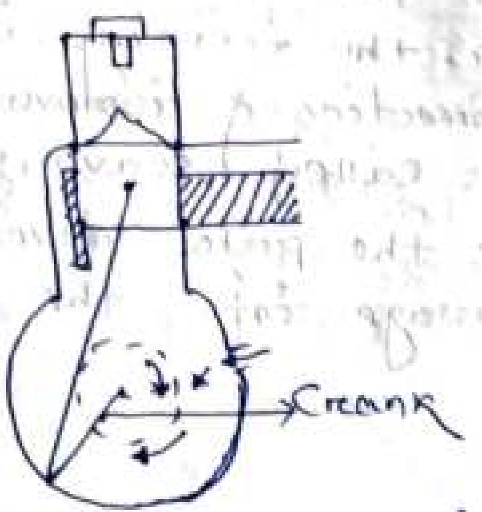
→ As the piston moves downward during expansion stroke, the exhaust port is opens & the burnt gases leaves ~~removes~~ from the cylinder to the atmosphere.

The slightly compressed charge in the Crank case passage through the transfer port & enters into the cylinder, then the cycle is completed.

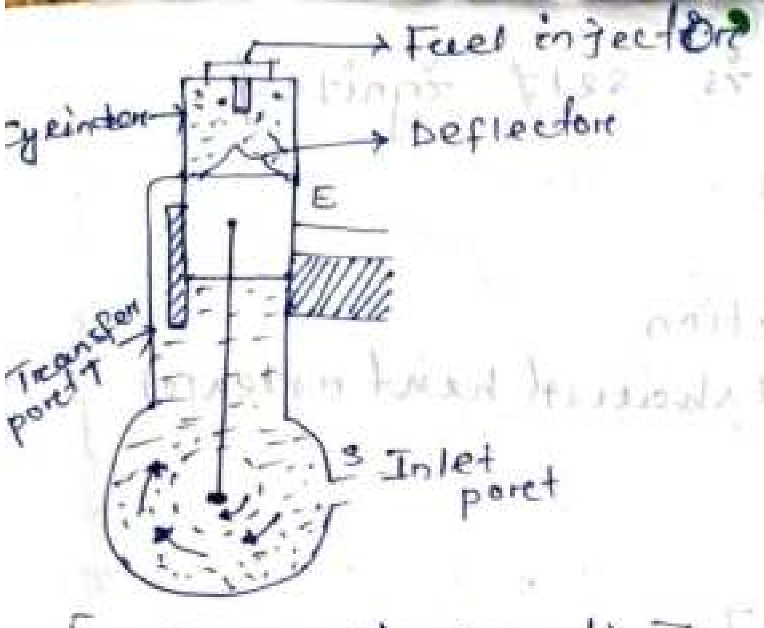
Two stroke diesel engine



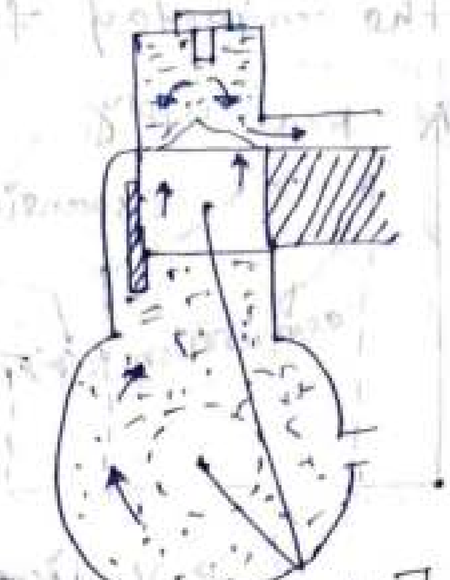
[(a) scavenging]



[(b) start of compression]



[(c) compression & suction]



[(d) Exhaust]

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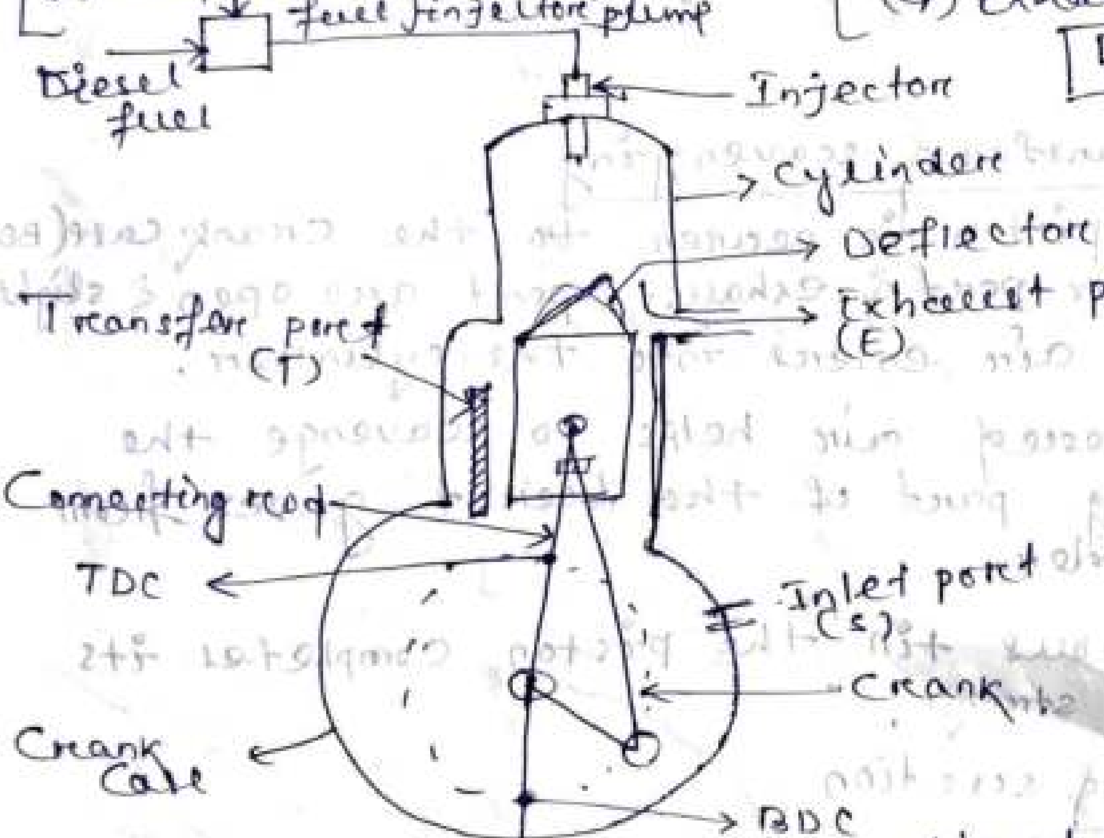
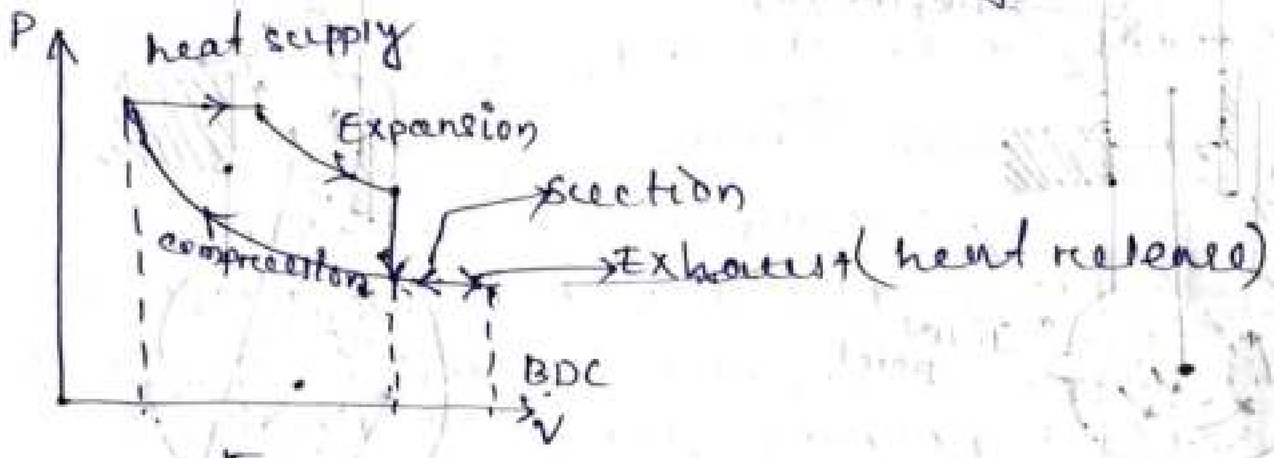


[Two stroke diesel engine]

Construction :-

- In this engine the only air (charge) during suction stroke is drawn into the cylinder and the fuel is injected through fuel injector at the end of compression stroke.
- This engine use a high compression ratio (i.e. 14-21).
- The temperature of intake air reaches at high at the end of compression.

→ So, the injected fuel is self ignited.



[P-V diagram]

Operation :-

① Charge transfer & scavenging

→ When the piston is nearer to the crank case (BDC), The transfer port & exhaust port are open & slightly compressed air enters into the cylinder.

→ The compressed air helps to scavenge the remaining part of the burnt gases from the cylinder.

→ It continuous till the piston completes its downward stroke.

② Compression & suction

→ In this operation both transfer port & exhaust port are closed by upward moving piston.

→ So, the air in the cylinder is compressed during forward stroke of the piston.

→ As the piston moves upward, a partially vaccume is created and the inlet port is open & fresh air enters into the cylinder.

③ Compression (power/Ignition)

→ At the end of compression stroke, the fuel is injected at very high pressure with the help of fuel pump & fuel injector.

→ The injected fuel is self ignited in the presence of hot air.

→ The piston moves downward by the high pressure burnt gases and power is transmitted to the crank case.

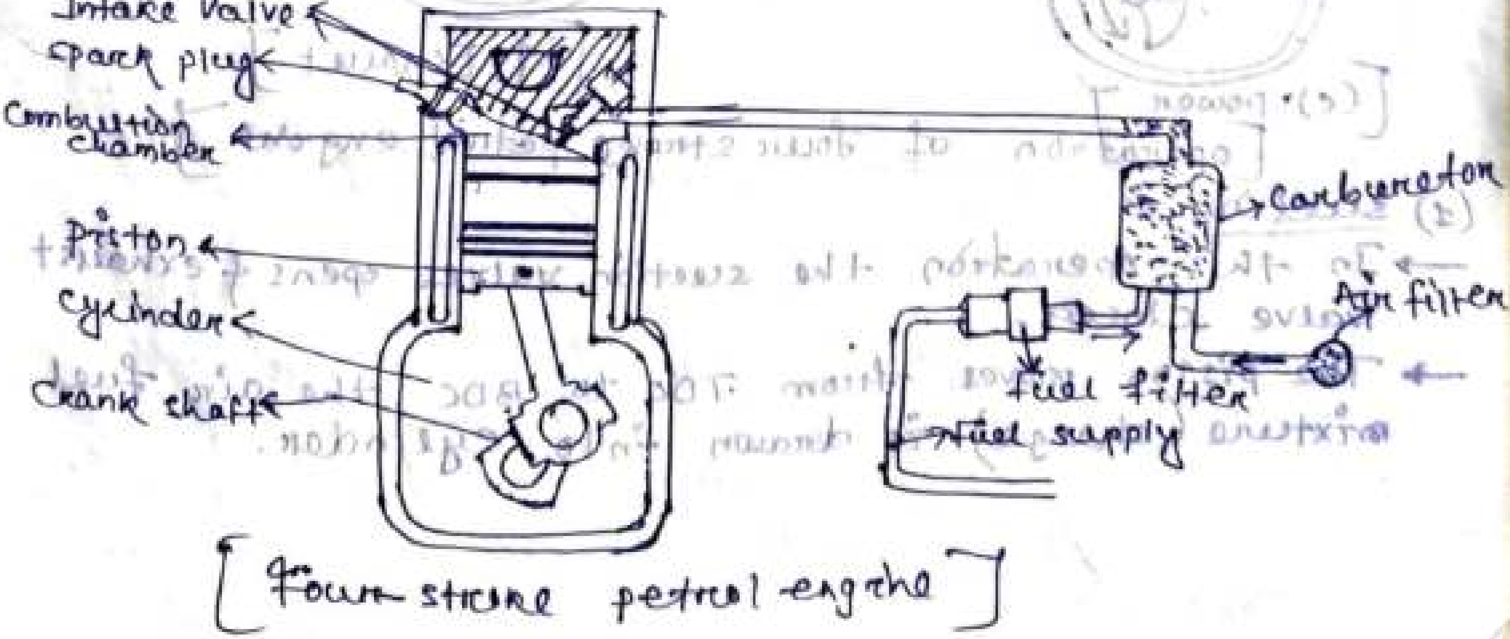
④ Exhaust

→ At the end of power stroke (expansion stroke), the exhaust port is opend & the exhaust gases leaves from the cylinder to the atmosphere.

The slightly compressed air passes into the cylinder through the transfer port, it continuous till it approches to the BDC, the cycle is completed.

Four strokes petrol engine :- DT-25.9.19

Construction :-



[Four stroke petrol engine]

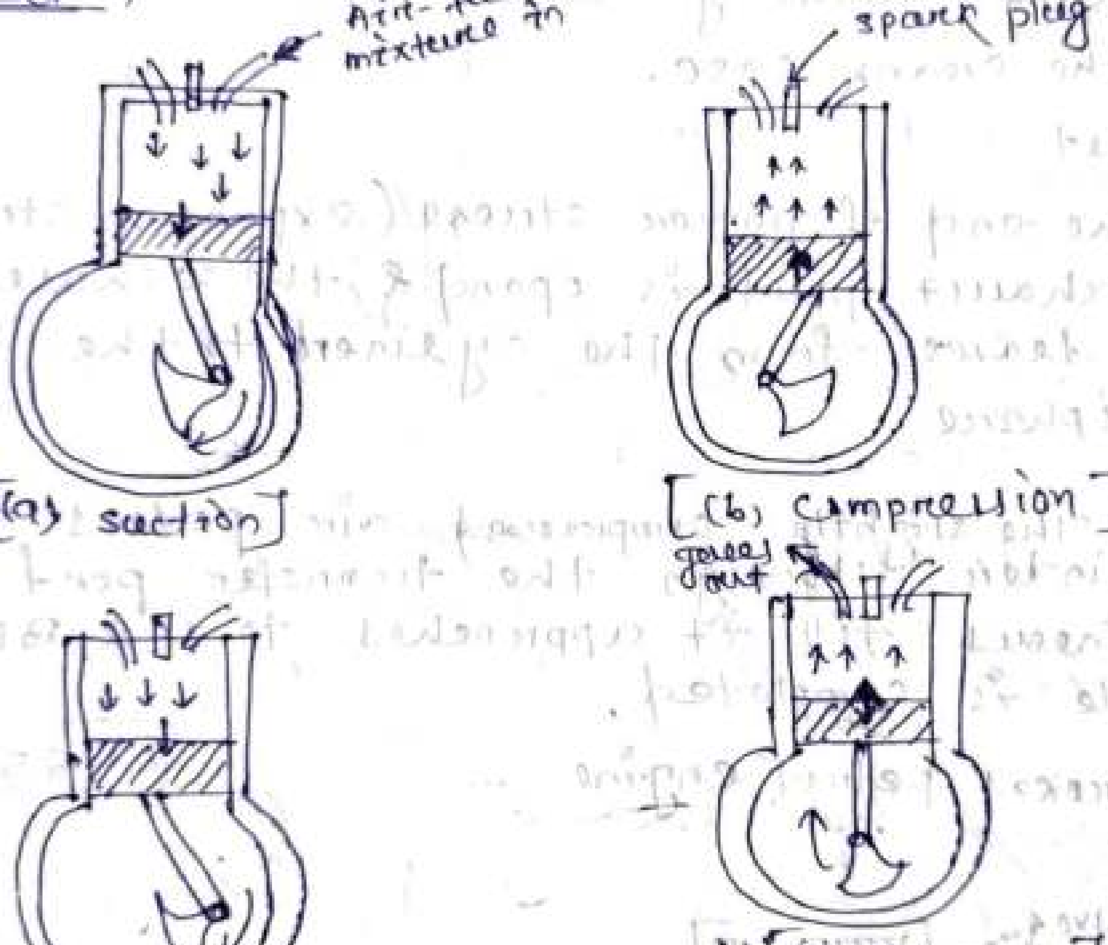
→ It consists of a cylinder, cylinder head, spark plug, connecting rod, piston, crank shaft etc.

→ In this engine the piston covers four strokes & crank shaft covers two revolution.

→ In this engine the valves are used instead of ports.

→ There are two valves are used (suction valve & exhaust valve) those are operated by cam shaft.

<u>Operation</u>



[(a) suction] [(b) compression] [(c) power] [(d) Exhaust]

[operation of four stroke petrol engine]

(1) <u>suction</u>

→ In this operation the suction valves opens & exhaust valve closed.

→ The piston moves from TDC to BDC, the air fuel mixture (charge) is drawn into cylinder.

(2) Compression :-

→ In this operation the piston moves from BDC to TDC and suction valve closed, exhaust valve also closed.

→ The charge inside the cylinder is compressed by the upward moving piston, it contineous till it reaches at TDC.

(3) Power :-

→ In this operation piston reaches at TDC & the high intensity spark plug ignites the charge and combustion takes place inside the cylinder.

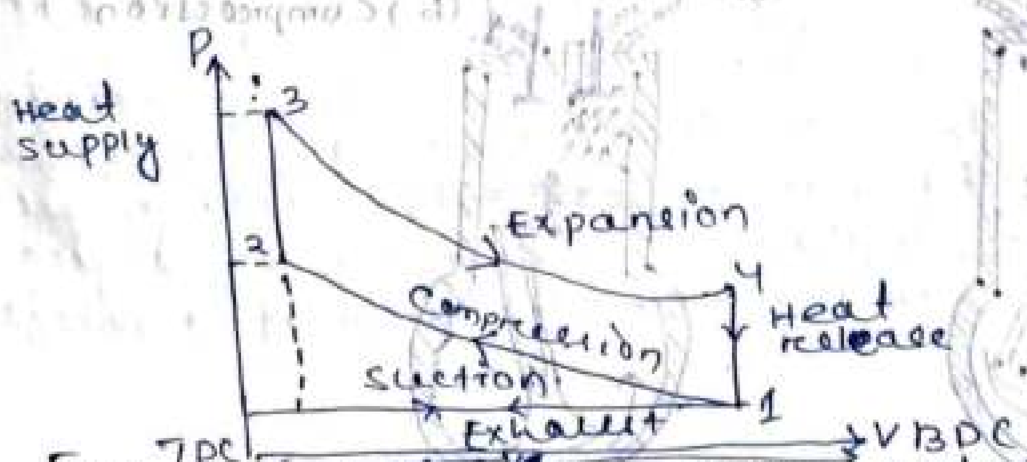
→ The burning of charge generates pressure in the cylinder.

(4) Exhaust :-

→ In this operation the piston moves downward due to pressure of burning gases & the exhaust valve opened.

→ The exhaust gases leave the ~~cylindd~~ cylinder to the atmosphere.

This stroke is completed when the piston approchgs the TDC then the cycle is completed.

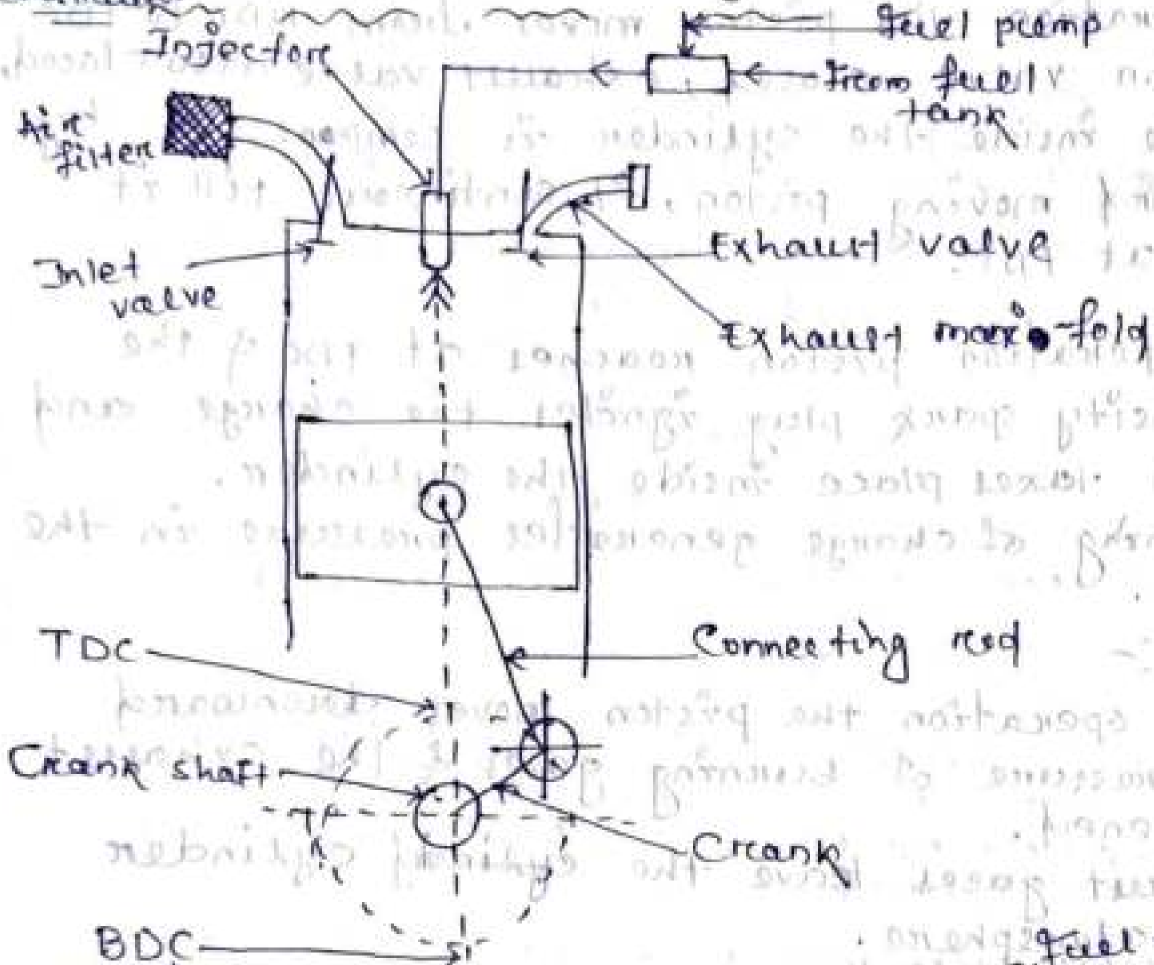


[P-V diagram of a four-stroke petrol engine]

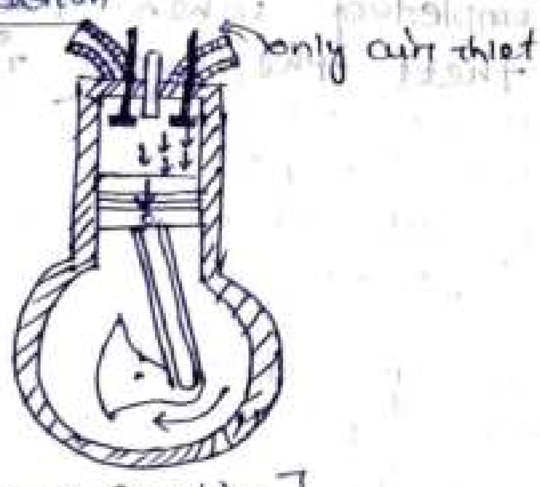
Dt-26.9.19

Four stroke diesel engine.

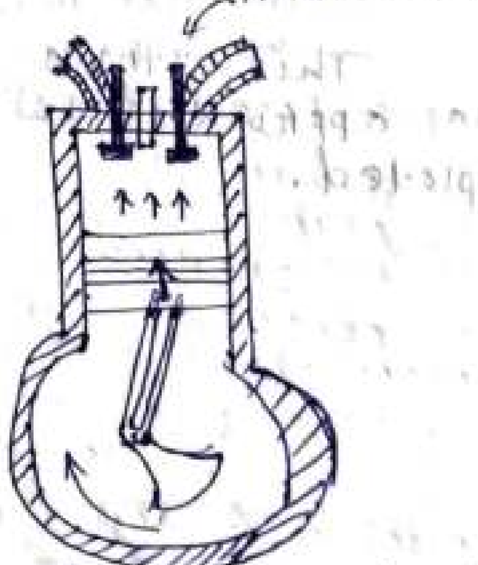
Construction



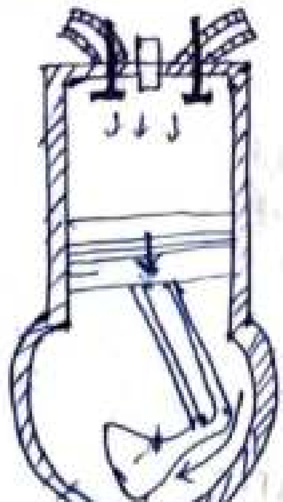
Operation



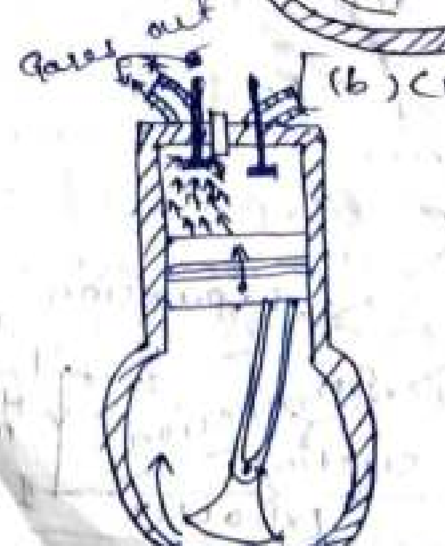
[(a) Suction]



[(b) Compression]



[(c) power]



[(d) Exhaust]

Construction :-

① This engine contains a fuel injector, fuel pump, cylinder, cylinder head, inlet & exhaust valves, piston, connecting rod, crank, crank shaft.

② In this engine, one cycle is completed for two revolutions of crank shaft, and 4 stroke of piston.

Operation :-

① suction :-

→ In this operation the suction valve (inlet valve) opens & the exhaust valve closed.

→ The only air is drawn into the cylinder from the TDC to BDC and this operation ends when the piston reaches at BDC.

② Compression :-

→ In this operation the piston moves from BDC to TDC, the inlet valve closed the exhaust valve also closed.

→ The air inside the cylinder is compressed till the piston reaches at TDC.

→ At the end of compression the fuel is injected at very high pressure into the compressed hot air and so the ignition starts inside the cylinder.

③ Power :-

→ In this operation both inlet valve & exhaust valve are closed, the piston moves from TDC to BDC due to expansion of burnt gases.

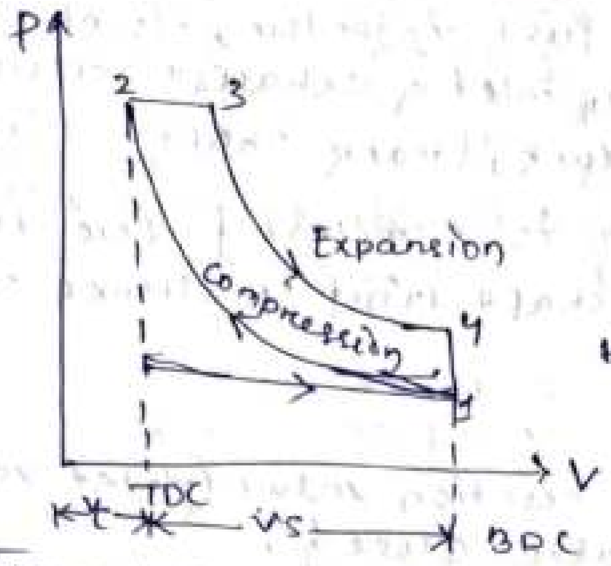
→ Due to high pressure of burnt gases, the power is generated (Expansion process).

④ Exhaust :-

→ In this operation, piston moves from BDC to TDC & the exhaust valve open & the inlet valve closed.

→ So the exhaust gases ~~moves~~ leaves from the cylinder to the atmosphere.

Thus the cycle is completed.



[V_c = Clearance volume
V_s = Swept volume]

[(b) P-V diagram of a four stroke diesel engine.]

Petrol Engine	Diesel Engine
(i) It operates on constant-volume cycle.	(i) It operates on constant-pressure cycle.
(ii) It uses gasolene or petrol as fuel.	(ii) It uses diesel & oils as a fuel.
(iii) The air-fuel mixture is prepared in the carburettor and inducted into the engine cylinder during the suction stroke.	(iii) The diesel engine takes in only air during the suction stroke, & it is compressed. At the end of the compression stroke the fuel is injected under the high pressure by a fuel injector.
(iv) The charge (air-fuel mixture) is ignited by a high-intensity spark produced at the spark plug.	(iv) Fuel is injected in very hot air, therefore it is self-ignited.
(v) It uses less compression ratio, usually range of 4 to 10.	(v) It uses high compression ratio, range of 14 to 21.
(vi) Lower & controlled rate of pressure rise; therefore operation is silent and smooth.	(vi) High rate of pressure variation, so engine operation is rough, and noisier.

(vii) For the same compression ratio, the efficiency of petrol engine is better.	(vii) It has lower efficiency for same compression ratio.
(viii) Comparatively lower pollution for same power output.	(viii) Higher pollution for same power output.
(ix) It has comparatively less number of parts, thus is less in weight.	(ix) It uses large number of sturdier parts, thus engine is heavy.
(x) Engines are cheaper.	(x) Costlier engine due to complicated parts.
(xi) It requires less & cheaper maintenance.	(xi) It requires costlier and large maintainance.
(xii) Very easy to start due to lower compression ratio.	(xii) Very difficult to start due to higher compression ratio.

Two-stroke Engine	Four-stroke Engine.
(i) There is one working stroke in each revolution. Hence engine has more even torque & reduced vibration.	(i) There is one working stroke in two revolutions. Hence engine has uneven torque & large vibration.
(ii) It uses ports & hence engine design is simple.	(ii) It uses valves, therefore, mechanism involved is complex.
(iii) The working cycle completes in one revolution & hence it has high mechanical efficiency.	(iii) Working cycle completes in two revolution, hence, it has more friction, thus less mechanical efficiency.
(iv) The burnt gases are not completely driven out. It results in dilution of fresh charge.	(iv) It has separate stroke for expulsion of burnt gases, thus ideally no dilution of fresh charge.
(v) Poor thermal efficiency due to poor scavenging & escaping of charge with exhaust gas.	(v) Very good thermal efficiency.
(vi) Less cost due to less parts in engine.	(vi) More cost due to large number of parts.
(vii) Cheaper & simple.	(vii) Costlier & slightly complex.
(viii) Lighter engine body	(viii) Heavier engine body.

CH-5

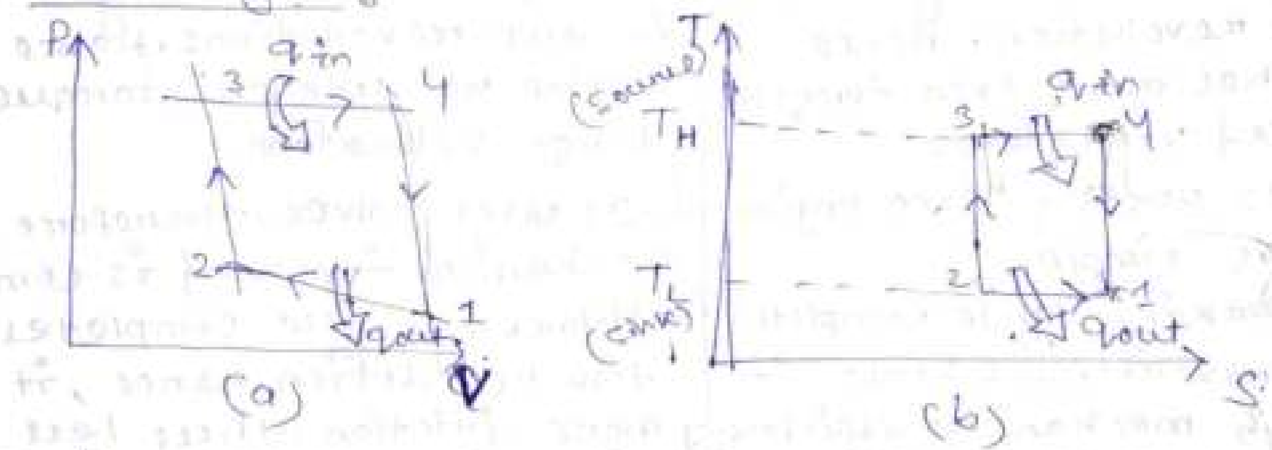
GAS POWER CYCLE

The devices producing net power output are called engines and they operate on thermodynamic cycles are called power cycles.

- Gas power cycle
  - Engine
    - Rotary
    - Reciprocating
      - Otto cycle (petrol engine) Ex:- Automobile, Aeroplane
      - Diesel cycle (Diesel engine) Ex:- Truck, buses, electric generating & Marine power plant.
      - Dual cycle (Both petrol & diesel engine.)
- Vapour power cycle

(V.V.I)

Carnot cycle :-



This cycle consist of 4 reversible processes

1. Isothermal heat addition
2. Isentropic expansion.
3. Isothermal heat rejection.
4. Isentropic compression.

The process during isothermal heat addition (3-4).

$$q_{in} = T_H (S_4 - S_3) \quad \text{——— (i)}$$

The process during isentropic expansion (4-1).

The heat is $q_{4-1} = 0$

$$S_4 = S_1$$

The process during isothermal heat rejection (1-2)

~~$q_{1-2} = 0$~~ $\quad q_{out} = T_L (S_1 - S_2)$ ——— (ii)

~~$S_1 = S_2$~~

The process during isentropic compression (2-3)

$$q_{2-3} = 0$$
$$S_2 = S_3$$

The net workdone per kg of air in the cycle

$$W_{net} = \Sigma q$$
$$= q_{in} - q_{out}$$
$$= T_H (S_4 - S_3) - T_L (S_1 - S_2)$$

$$\boxed{W_{net} = (T_H - T_L)(S_1 - S_2)}$$

Thermal efficiency of carnot cycle is

$$= \frac{W_{net}}{q_{in}}$$

$$= \frac{(T_H - T_L)(S_1 - S_2)}{T_H (S_4 - S_3)}$$

$$= \frac{(T_H - T_L)(S_1 - S_2)}{T_H (S_1 - S_2)}$$

$$= \frac{T_H - T_L}{T_H} = \boxed{1 - \frac{T_L}{T_H}}$$

~~This cycle~~

The efficiency of this cycle is more than the efficiency of actual & ideal cycle.

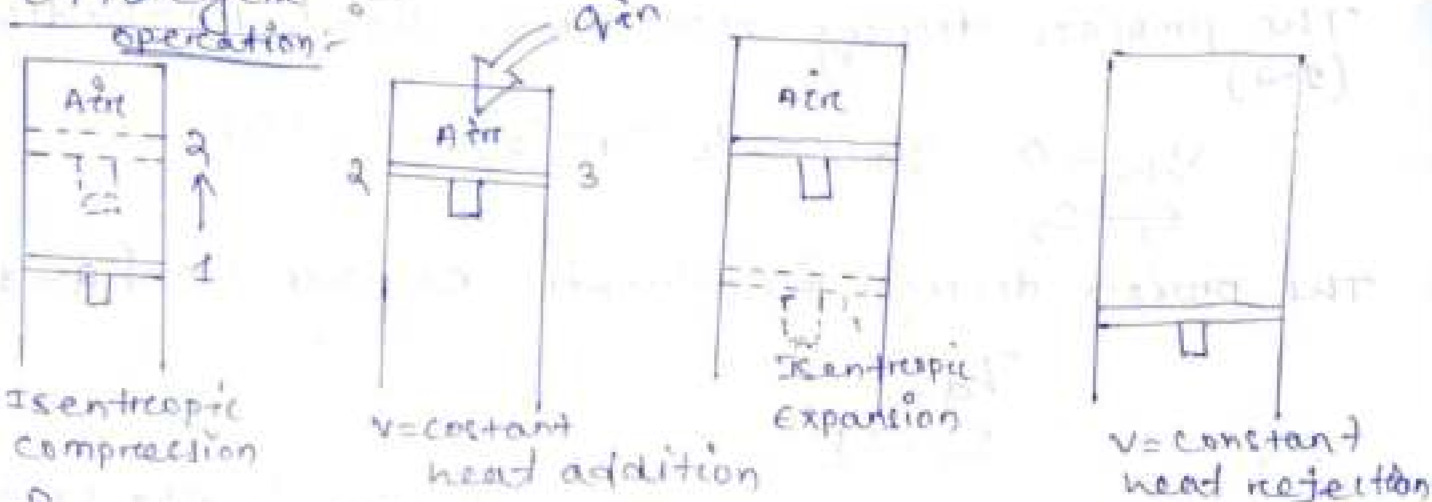
It also conveys when the thermal efficiency increases, the average temperature also increases with heat addition to the system.

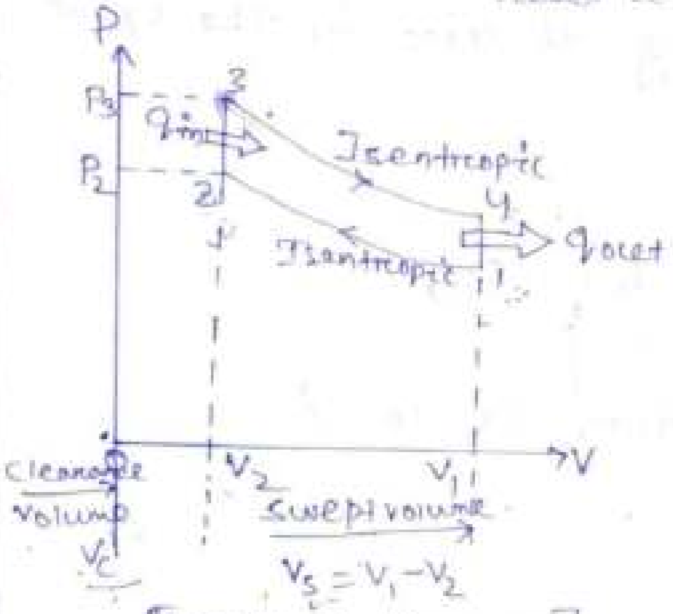
When the thermal efficiency decreases the average temperature also decreases with heat rejection from the system.

[Dt - 3.10.19]

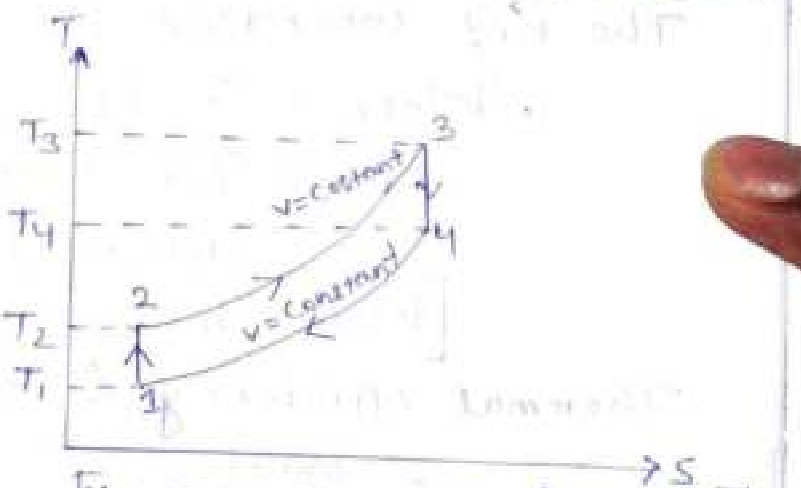
Otto cycle :-

operation :-





[(a) P-V diagram]



[(b) T-S diagram for air standard otto cycle.]

This cycle is used for petrol engine, gas engine & high speed engine.

This cycle consist of 4 processes.

1. 1-2 - Isentropic compression
2. 2-3 - Heat addition at constant volume
3. 3-4 - Isentropic Expansion
4. 4-1 - Heat rejection at constant volume.

Analysis :-

For otto cycle, heat addition at constant volume $= q_{in\,(2-3)} = C_v(T_3 - T_2)$ ——(i)

Heat rejection at constant volume

$= q_{out\,(4-1)} = C_v(T_4 - T_1)$ ——(ii)

$\therefore$ Net work done $= \Sigma q$

$= q_{in} - q_{out}$

$= \boxed{C_v(T_3 - T_2) - C_v(T_4 - T_1)}$

~~$= C_v T_3$~~

Thermal efficiency $= \dfrac{W_{net}}{q_{in}}$

$= \dfrac{C_v(T_3 - T_2) - C_v(T_4 - T_1)}{C_v(T_3 - T_2)}$

$= 1 - \dfrac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)}$

$= \boxed{1 - \left(\dfrac{T_4 - T_1}{T_3 - T_2}\right)}$ ——(iii)

Considering the isentropic compression process (1-2)

$\dfrac{T_2}{T_1} = \left(\dfrac{V_1}{V_2}\right)^{\gamma - 1} = r^{\gamma - 1}$ ——(iv) $\boxed{\dfrac{V_1}{V_2} = \text{Compression ratio}}$

For the isentropic expansion process (3-4).

$\dfrac{T_3}{T_4} = \left(\dfrac{V_4}{V_3}\right)^{\gamma - 1}$ ——(v)

$= r^{\gamma - 1}$

Equating the eqn-(iv) & (v) we get.

$\boxed{\dfrac{T_2}{T_1} = \dfrac{T_3}{T_4}}$ or $\boxed{\left(\dfrac{V_1}{V_2}\right)^{\gamma - 1} = \left(\dfrac{V_4}{V_3}\right)^{\gamma - 1}}$

Putting the value of previous eq^n in eq^n – (iii)

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = \frac{T_4}{T_1} = \frac{T_3}{T_2} \quad \left(\because \frac{T_2}{T_1} = \frac{T_3}{T_4}\right)$$

$$\eta_{otto} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$= 1 - \frac{\left(\frac{T_4}{T_1} - 1\right) \times T_1}{\left(\frac{T_3}{T_2} - 1\right) \times T_2}$$

$$= 1 - \frac{T_1}{T_2}$$

$$= 1 - \frac{1}{\frac{T_2}{T_1}} = 1 - \frac{1}{r^{\gamma - 1}}$$

Q. In an engine working an Ideal otto cycle, the temperatures at the begning and at the end of compression are 27°C and 327°C. Find the compression ratio & air-standard efficiency of the engine.

Sol^n. Given data.

$T_1 = 27°C + 273 K = 300 K$

$T_2 = 327°C + 273 K = 600 K$

Constant specific heats & its ratio $\gamma = 1.4$.

petrol – SI (spark ignition) diesel – CI (compression ignition)

(i) The compression ratio

$$r = \frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}} = \left(\frac{600}{300}\right)^{\frac{1}{1.4-1}} = 5.65$$

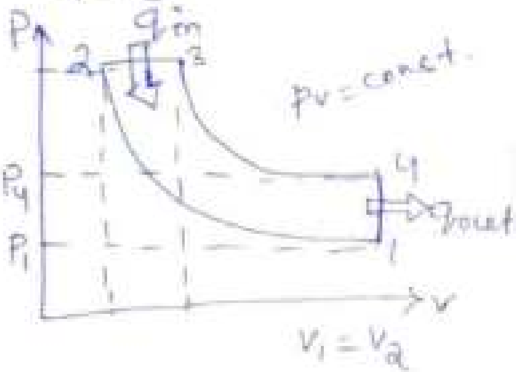
(ii) Thermal efficiency of the engine

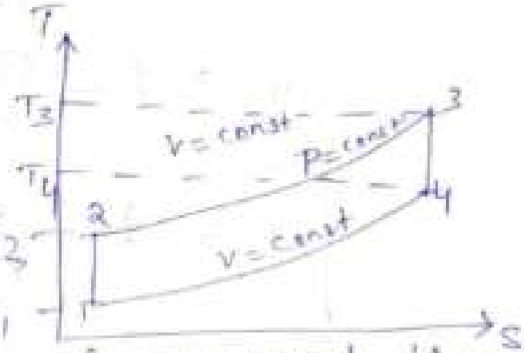
$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(5.65)^{1.4-1}} = 0.499 \simeq 0.5$$
$$= 50\%.$$

Dt - 15.10.19

Diesel cycle

$P_2 = P_3$





Air standard diesel cycle

- The diesel cycle is used in CI engine.
- In this cycle the only air is compressed during the compression stroke.
- It has high compression ratio (12–24). $r = \frac{V_1}{V_2}$

This cycle consist of four process.

1. Isentropic compression
2. Reversible constant pressure heat addition.
3. Isentropic expansion
4. Reversible constant volume heat rejection.

Derivation:-

For 1 kg. air in a Diesel cycle.

Heat supplied $q_{in}(2-3) = C_p(T_3 - T_2)$ ——(i)

Heat rejection $q_{out}(4-1) = C_v(T_4 - T_1)$ ——(ii)

$$\eta_{Diesel\,cycle} = \frac{\text{Workdone}}{\text{Heat supply}}$$

$$= \frac{q_{in} - q_{out}}{q_{in}}$$

$$= 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{1(T_4 - T_1)}{\gamma(T_3 - T_2)}$$ ——(iii)

Process (1-2) Isentropic compression

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r_c^{\gamma-1}$$ ——(iv) → compression ratio

Process (2-3) at constant pressure

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho \text{ (cut-off ratio)}$$ ——(v)

Process (3-4) Isentropic expansion

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$ ——(vi)

Process (4-1) at constant volume

$$\frac{T_4}{T_1} = \frac{V_4}{V_1}$$

From eqn (iv)

$$T_1 = \frac{T_2}{r_c^{\gamma-1}}$$

$$T_2 = T_1 r_c^{\gamma-1}$$

From eq^n-(v)

$$T_3 = \rho \frac{T_2 v_3}{v_2} = \rho r^{\gamma-1} T_1$$

From eq^n-(vi)

$$T_4 = \left(\frac{V_3}{V_4}\right)^{\gamma-1} T_3$$

$$= \left(\frac{V_3}{V_1}\right)^{\gamma-1} T_3 \quad (\because v_1 = v_4)$$

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

$$= \rho^{\gamma} T_1$$

Putting all these value in eq^n-(iii) we get:

$$\eta_{diesel\ cycle} = 1 - \frac{1(T_4 - T_1)}{\gamma(T_3 - T_2)}$$

~~01-16.10.19~~

$$= 1 - \frac{1\left[\left(\frac{v_3}{v_4}\right)^{\gamma-1} T_3 - T_1\right]}{\gamma\left[\frac{T_2 v_3}{v_2} - T_1 r^{\gamma-1}\right]}$$

$$= 1 - \frac{1\left(\frac{v_3}{v_2} \times \frac{v_2}{v_1}\right)^{\gamma-1}(T_3 - T_1)}{\gamma\left(\rho r^{\gamma-1} T_1 - T_1 r^{\gamma-1}\right)} \quad \left[\because v_4 = v_1\right]$$

$$= 1 - \frac{1(\rho^{\gamma} T_1 - T_1)}{\gamma(\rho r^{\gamma-1} T_1 - T_1 r^{\gamma-1})}$$

$$= 1 - \frac{T_1(\rho^{\gamma} - 1)}{\gamma T_1(\rho r^{\gamma-1} - r^{\gamma-1})}$$

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

[Dt-16.10.19]

Q. An air standard Diesel cycle has a compression ratio of 14. The pressure at the beginning of the compression stroke is 1 bar & the temperature is 300K. The maximum cycle temperature is 2500K. Determine the cut-off ratio & thermal efficiency.

Soln. Given data.

Compression ratio $(r) = 14$

$P_1 = 1\text{ bar} = 100\text{ kP}$, $T_1 = 300\text{K}$.

$T_3 = 2500\text{K}$.

$$T_2 = T_1 (r)^{\gamma-1}$$
$$= 300 \times (14)^{1.4-1} = 862.129\text{ K}.$$

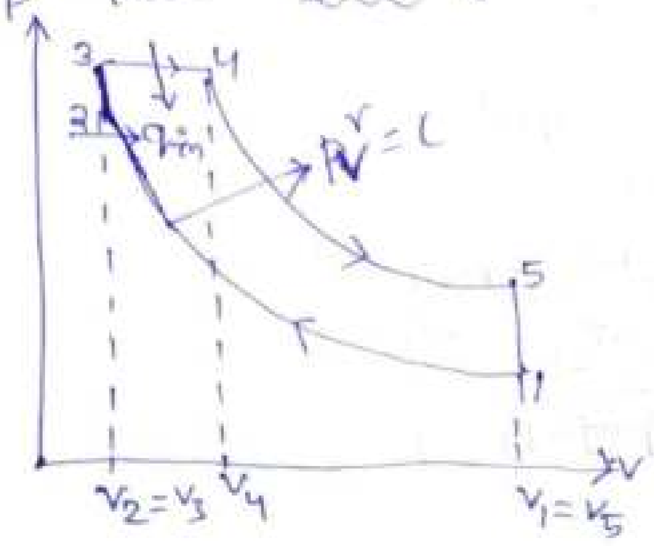
$$\text{Cut-off ratio } (\rho) = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{2500}{862.129} = 2.89$$

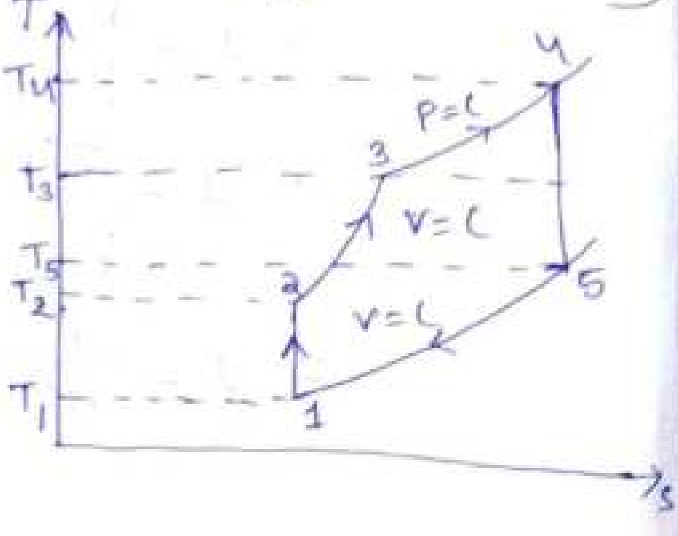
$$\text{Thermal efficiency } (\eta)_{Diesel} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^\gamma - 1}{\gamma(\rho - 1)}\right]$$

$$= 1 - \frac{1}{(14)^{1.4-1}}\left[\frac{(2.89)^{1.4} - 1}{1.4 \times (2.89 - 1)}\right]$$

$$= 0.55 = 55\%$$

Diesel cycle :





[γ- Isentropic index]

Dual cycle :-

In this cycle the fuel injection starts before the end of compression stroke.

So, a part of heat is added at constant volume & at constant pressure.

Derivation

Heat supplied (q_{in}) (2-4 process)

$$= C_v(T_3 - T_2) + C_p(T_4 - T_3) \quad \text{—— (i)}$$

Heat rejection (q_{out}) (5-1) $= C_v(T_5 - T_1)$ —— (ii)

$$\eta_{Dual} = \frac{\text{Work done}}{\text{Heat supply}}$$

$$= \frac{q_{in} - q_{out}}{q_{in}}$$

$$= 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)} \quad \text{—— (iii)}$$

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

Expansion ratio $= r_e = \frac{V_5}{V_4}$

Pressure ratio $= \frac{P_3}{P_2} = r_p$

Compression ratio $r = \frac{V_1}{V_2}$

Process (1-2) Isentropic Compression

$$\frac{T_2}{T_1} = r^{\gamma-1}$$

$$\Rightarrow \boxed{T_2 = r^{\gamma-1} T_1} \quad \text{—— (iv)}$$

$$\boxed{T_1 = \frac{T_2}{r^{\gamma-1}}} \quad \text{—— (v)}$$

Processes (2-3) heat addition at constant volume.

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = r_{cp}$$

$$\Rightarrow \boxed{T_2 = \frac{T_3}{r_{cp}}} \quad \text{—(vi)}.$$

$$\Rightarrow \boxed{T_3 = T_2 r_{cp}} \quad \text{—(vii)}$$

process (3-4) heat addition at constant pressure.

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

$$\Rightarrow \boxed{T_3 = \frac{T_4}{\rho}} \quad \text{—(viii)}$$

$$\Rightarrow \boxed{T_4 = T_3 \rho} \quad \text{—(ix)}.$$

Process (4-5) Isentropic expansion

$$\boxed{\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{1}{r_e}\right)^{\gamma-1}} \quad \text{—(x)}.$$

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{V_4}{V_1}\right)^{\gamma-1}$$

$$= \left(\frac{V_4}{V_1}\right)^{\gamma-1} = \left(\frac{V_3 \times V_2}{V_3 \times V_2} \times \frac{V_4}{V_1}\right)^{\gamma-1}$$

$$= \left(\frac{V_4}{V_3} \times \frac{V_2}{V_1} \times \frac{V_3}{V_3}\right)^{\gamma-1} \left[\because V_3 = V_2\right]$$

$$= \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$\Rightarrow \boxed{T_4 = \frac{T_5}{\left(\frac{\rho}{r}\right)^{\gamma-1}}} \quad \text{—(xi)}$$

$$\Rightarrow \boxed{T_5 = \left(\frac{\rho}{r}\right)^{\gamma-1} T_4} \quad \text{—(xii)}$$

(51)

putting all these values in eq^n-(iii)

$$\eta_{Dual} = 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{T_5 - T_1}{T_3 - T_2 + \gamma(T_4 - T_3)}$$

$$= 1 - \frac{(r_{cp}\, f^{\gamma} T_1 - T_1)}{(T_1 r_{cp} r_c^{\gamma-1} - T_1 r_c^{\gamma-1}) + [\gamma(f r_c^{\gamma-1} T_1 r_{cp} - T_1 r_c^{\gamma-1} r_{cp})]}$$

$$T_5 = T_4 \times \left(\frac{f}{r_c}\right)^{\gamma-1}$$
$$= f T_3 \times \left(\frac{f}{r_c}\right)^{\gamma-1}$$
$$= f T_2 r_{cp} \times \left(\frac{f}{r_c}\right)^{\gamma-1}$$
$$= f r_{cp} T_1 r_c^{\gamma-1} \times \left(\frac{f}{r_c}\right)^{\gamma-1}$$
$$= f r_{cp} T_1 \frac{f^{\gamma}}{f}$$
$$= r_{cp} f^{\gamma} T_1$$

$$= 1 - \frac{T_1(r_{cp} f^{\gamma} - 1)}{T_1[r_{cp} r_c^{\gamma-1} - r_c^{\gamma-1} + \gamma(f r_c^{\gamma-1} r_{cp} - r_c^{\gamma-1} r_{cp})]}$$

$$= 1 - \frac{r_{cp} f^{\gamma} - 1}{r_c^{\gamma-1}(r_{cp} - 1) + \gamma r_c^{\gamma-1} r_{cp}(f - 1)}$$

$$= 1 - \frac{1}{r_c^{\gamma-1}}\left[\frac{r_{cp} f^{\gamma} - 1}{(r_{cp} - 1) + \gamma r_{cp}(f - 1)}\right]$$

When $r_{cp} = 1$ then

$\eta_{Diesel} = \eta_{Dual}$.

when $r_{cp} = 1$, $f = 1$ then

$\eta_{Otto} = \eta_{Diesel}$.

Bela 7/10/19

CH-6 fuels & Combustion | Dt-21.10.19

→ fuel is a combustable substance & it burns in the presente of oxygen and release heat energy.

→ It has 3 types
(1) solid (2) Liquid (3) Gas.

→ Each fuel consist of certain amount of bounded energy (chemical energy) & it also called internal energy.

→ During combustion, the bonds between molecules of fuel are broken & the arrangement of new molecules takes place then the heat energy is release.

Characteristics of ideal fuel:-

(i) It should have a high hitting value.
(ii) It should be free from moisture.
(iii) It should be easy to transport & store in minimum space.
(iv) It should have high combustion efficiency.
(v) It should be readly available at low cost.
(vi) It should have control combustion.

Different types of fuels

1. Solid fuels (Coal):-

→ It is a solid fuel & it contain Carbon, oxygen, hydrogen, nitrogen, sulphour, moisture.

→ It passes two different stages during its formation.

Coal
- → Peat [30% moisture & it is used in gas produces plants]
- → Lignite [60% Carbon & used in Nuclear power plant]
- → Bituminous [70% carbon & used in gas produces plants]
- → Anthracite [90% Carbon & used in steam power plant]
- → Wood charcoal [Used in furnance]
- → Coke [90-95% carbon & used in steam power plant]
- → Briquetters [Used in furnance]
- → Pulverised [Crushed coal in fine powder form
Used in cement industries.]

Dt - 22.10.19

2. Liquid fuel :-

1. Benzol :-
It consist of benzene (C_6H_6) and toulene (C_7H_8) and is obtained as a by-product of high temp. coal carbonization and heating value is low.

2. Alcohol :-
- → It has good anti-knock qualities.
- → Its heating value is ~~high~~ low as compared to gasoline.
- → It is more expensive to produce.

3. Refined products of petroleum :-
- → It is the main source of liquid fuels for I.C. engines.
- → It is used in form of gasoline, kerosene, and diesel oil.

3. Gaseous fuels :-

These fuels are used in S.I engines. The different gaseous fuels are enumerated and discussed below.

1. Natural gas.
2. Manufactured gases.
3. By-product gases
4. Sewage sludge gas.
5. Bio-gas

1. Natural gas :-

→ Its composition varies with source but mainly it contains CH_4 (70 to 90%) and remaining C_2H_6 and N_2.

~~Manufactured gas :-~~

→ It is available with oil wells and is colourless and odourless.

→ It is found in several parts of the world. but particularly in USA it also carried from the place of availability to the place of use through hundred of kilometers pipeline

2. Manufactured gases :-

→ Coal gas is manufactured by heating soft coal in closed vessel.

→ Water gas is formed by using steam.

3. By-product gases :-

The gases produced during manufacture of other substances are known as by-product gases.

→ Blast furnace gas is by-product of steel plants. It contain CO & N_2. It contain large amount of dust particles.

4. sewage sludge gas :-

→ It contain CH_4 & CO_2 with very small percentage of H_2S.

→ This gas is made available from present well developed sewage disposal plants.

5. Bio-gas :-

→ This gas is produced from the cow dung which is available in large quantities in India.

→ It is easy to produce (with appropriate chemical reaction) and use locally.

Dt - 23.10.1

Heating values of fuel (calorific value)(h_c):-

It is defined as the amount of heat energy released by complete combustion of unity quantity of fuel.

Unit

KJ/kg → for solid fuel & liquid fuel

KJ/m³ → for gaseous fuel.

→ The calorific value of fuel is the absolute enthalpy value of formation.

→ By convention the calorific value is (+)ve but it has opposite sign for absolute enthalpy formation.

Quality of Engine fuels :-

Spark Ignition (S.I) Engine (petrol engine):-

① Volatility

→ It is the main characteristic of petrol engine.

→ The measuring of fuel volatility is the distillation of fuel in a special device at atmospheric pressure

② Starting and warm up.

→ ~~When the~~ A certain part of the S.I engine, the gasoline should vapourised at room temp. for easy starting of the engine.

→ As the engine warms up, the temp. will gradually increase to the operating temp.

③ Operating range of performance

→ To obtained good vapourization of gasoline low distillation temp. are preferred for engine operating range.

→ Better vapourization also produces more uniform distribution of fuel to the cylinder.

④ Crankcase dilution

→ The liquid fuel in the cylinder causes the loss of lubricating ~~fuel~~ oil which damage the cylinder wall & increases friction.

→ The liquid gasoline also dilute the lubricating oil to prevent friction.

⑤ Vapour lock characteristics

→ This characteristics demands the presence of high boiling temp. of hydrocarbon throughout the distillation range.

→ It is also required because high rate of vapourization of gasoline stops the fuel flow to the engine.

⑥ Anti knock quality

→ The abnormal burning of I.C. engine in combustion chamber causes very high rate of energy release, pressure, temp. & also affects the thermal efficiency.

→ So, the anti knock property is required to increase the thermal efficiency & power output

→ The anti knock property of fuel depends on the air fuel mixture, chemical composition & molecular str. of the fuel.

(7) Gum deposits

→ The gasoline contains hydrocarbons of the paraffin, napthene & aromatic families form little gum.

→ The amount of gum increases with raise of temp. ; exposure to sunlight & the gum will cause the operating difficulties in engine.

(8) sulphur Content

→ The sulphur is a corrosive element of the fuel which damage the carburetor & fuel injection Come.

→ ~~So~~ since the sulphur has a low ignition temp. in the S.I engine: it promots locking