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CONTENT

SUBJECT CODE &SUBJECT: 4020340, THERMAL ENGINEERING I

1. NOTES OF LESSON INDEX PAGE

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NOTES OF LESSON – INDEX PAGE

YEAR:	II	SEMESTER:	III
SUBJECT CODE &SUBJECT	4020340-THERMAL ENGINEERING I	SCHEME:	N SCHEME

UNIT: I - **Basics of Thermodynamics and Thermodynamic processes of Perfect Gases**

S.NO	TOPIC	REFER TEXT BOOK NAME	VIDEO PRESENTATION	PPT	ANY OTHER
1	Introduction	N.V PUBLICATION-TEXT BOOK	-	PPT	-
2	definitions and units of mass, weight, volume, density,work –power-energy	N.V PUBLICATION-TEXT BOOK	-	PPT	-
3	heat –specific heat capacity at constant volume and at constant pressure	N.V PUBLICATION-TEXT BOOK	-	PPT	-
4	thermodynamic system–types –thermodynamic equilibrium - properties of systems	N.V PUBLICATION-TEXT BOOK	-	PPT	-
5	zeroth, first and second laws of thermodynamics	N.V PUBLICATION-TEXT BOOK	-	PPT	-
6	Perfect gases – laws of perfect gases – Boyles, Charles, Joules, Regnaults and Avogadros laws	N.V PUBLICATION-TEXT BOOK	-	PPT	-
7	General Gas Equation characteristic gas equation – relation between specific heats and gas constant –	N.V PUBLICATION-TEXT BOOK	-	PPT	
8	universal gas constant – Thermodynamic Processes-Change in Internal Energy	N.V PUBLICATION-TEXT BOOK	-	PPT	-
9	enthalpy –change in enthalpy – entropy – change in entropy	N.V PUBLICATION-TEXT BOOK	-	PPT	-

10	general equations for change in entropy	N.V PUBLICATION-TEXT BOOK	-	PPT	-
11	Constant volume, pressure process	N.V PUBLICATION-TEXT BOOK	-	-	HAND NOTES
12	isothermal, isentropic process	N.V PUBLICATION-TEXT BOOK	-	-	HAND NOTES -
13	Polytropic process	N.V PUBLICATION-TEXT BOOK	-	-	HAND NOTES
14	P-V and T-S diagrams, work done, change in internal energy, heat transfer	N.V PUBLICATION-TEXT BOOK	-	PPT	-
15	Free expansion and throttling processes.	N.V PUBLICATION-TEXT BOOK	-	PPT	-

UNIT: II - THERMODYNAMIC AIR CYCLES AND HEAT TRANSFER

S.NO	**TOPIC**	**REFER TEXT BOOK NAME**	**VIDEO PRESENTATION**	**PPT**	**ANY OTHER**
1	Air cycles	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
2	air standard efficiency – reversible and irreversible processes	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
3	Carnot cycle	N.V PUBLICATION-TEXT BOOK	**-**	**-**	**HAND NOTES**
4	Otto cycle	N.V PUBLICATION-TEXT BOOK	**-**	**-**	**HAND NOTES**
5	Diesel cycle	N.V PUBLICATION-TEXT BOOK	**-**	**-**	**HAND NOTES**
6	Modes of heat transfer	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
7	heat transfer by conduction	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
8	Fourier’s Law-– heat transfer by convection	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
9	heat exchanger – Parallel flow and Counter flow	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
10	heat transfer by radiation	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
11	Steady flow system	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
12	control volume	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	

13	steady flow energy equation	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	
14	Engineering applications of steady flow energy equation	N.V PUBLICATION-TEXT BOOK	-	**PPT**	
15	non flow energy equation.	N.V PUBLICATION-TEXT BOOK	-	**PPT**	

UNIT III- INTERNAL COMBUSTION ENGINES

S.NO	**TOPIC**	**REFER TEXT BOOK NAME**	**VIDEO PRESENTATION**	**PPT**	**ANY OTHER**
1	Internal combustion engines.	N.V PUBLICATION-TEXT BOOK		PPT	
2	Classifications of I.C Engines –components of I.C Engines	N.V PUBLICATION-TEXT BOOK		-	-
3	Two stroke petrol engine	N.V PUBLICATION-TEXT BOOK	https://www.youtube.com/watch?v=XKcRf2R5h4o	-	-
4	four stroke petrol engine	N.V PUBLICATION-TEXT BOOK	https://www.youtube.com/watch?v=emSXIJwGfQU	-	-
5	Two stroke diesel engine	N.V PUBLICATION-TEXT BOOK	https://www.youtube.com/results?search_query=2+stroke++DISEL+engine+	-	-
6	four stroke diesel engine	N.V PUBLICATION-TEXT BOOK	https://www.youtube.com/watch?v=fTAUq6G9apg&t=8s	-	**-**
7	Valve timing diagram for four stroke petrol and diesel engine	N.V PUBLICATION-TEXT BOOK	**-**	PPT	**-**
8	port timing diagram for two stroke petrol and diesel engines.	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	**-**
9	Layout of fuel supply system in petrol engines	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
10	Ignition systems	N.V PUBLICATION-TEXT BOOK	**-**	**PPT**	**-**
11	Governing of I.C. engines	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
12	quantity and quality governing	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-

13	Cooling systems – air cooling – water cooling	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
14	Lubrication system	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
15	oil pump (Gear & Rotor Pumps) and oil filters.	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-

UNIT:IV - FUELS &COMBUSTION OF FUELS AND PERFORMANCE OF I.C ENGINES

S.NO	**TOPIC**	**REFER TEXT BOOK NAME**	**VIDEO PRESENTATION**	**PPT**	**ANY OTHER**
1	Classifications of fuels	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
2	requirements of a good fuel – combustion equations	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
3	stoichiometric air required for complete combustion of fuels – excess air	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
4	products of combustion	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
5	Exhaust gas analyser	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
6	Bomb and Junker's calorimeter	N.V PUBLICATION-TEXT BOOK	**https://www.youtube.com/watch?v=wwJG2JVg6qM&t=10s**	-	-
7	Testing - thermodynamic and commercial tests	N.V PUBLICATION-TEXT BOOK	-	-	**HAND NOTES**
8	indicated power –brake power	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
9	efficiencies of I.C. engines	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
10	Indicated thermal ,brake thermal, mechanical and relative efficiencies	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
11	Specific fuel consumption	N.V PUBLICATION-TEXT BOOK	-	**PPT**	-
12	problems	N.V PUBLICATION-TEXT BOOK	-	-	**HAND NOTES**
13	problems	N.V PUBLICATION-TEXT BOOK	-	-	**HAND NOTES**
14	Morse test – heat balance sheet – procedure and problems.	N.V PUBLICATION-TEXT BOOK	-	-	**HAND NOTES**
15	problems	N.V PUBLICATION-TEXT BOOK	-	-	**HAND NOTES**

UNIT V- REFRIGERATION AND AIR CONDITIONING

S.NO	TOPIC	REFER TEXT BOOK NAME	VIDEO PRESENTATION	PPT	ANY OTHER
1	Refrigeration	N.V PUBLICATION-TEXT BOOK	-	PPT	-
2	refrigerators and heat pumps	N.V PUBLICATION-TEXT BOOK	-	PPT	-
3	types and applications of refrigeration Systems – refrigerating effect	N.V PUBLICATION-TEXT BOOK	-	PPT	-
4	C.O.P of refrigerator, heat pump & Heat Engines	N.V PUBLICATION-TEXT BOOK	-	PPT	-
5	Vapour compression refrigeration system	N.V PUBLICATION-TEXT BOOK	**https://www.youtube.com/watch?v=PjcdqAkP0UA**	-	-
6	Vapour absorption system	N.V PUBLICATION-TEXT BOOK	**https://www.youtube.com/watch?v=1p6dgGVnS2w**	-	-
7	Comparision - refrigerants – properties.	N.V PUBLICATION-TEXT BOOK	-	PPT	-
8	Psychrometry - psychometric properties	N.V PUBLICATION-TEXT BOOK	-	PPT	-
9	sensible heating and cooling	N.V PUBLICATION-TEXT BOOK	-	PPT	-
10	humidification – dehumidification	N.V PUBLICATION-TEXT BOOK	-	PPT	-
11	Air conditioning	N.V PUBLICATION-TEXT BOOK	-	PPT	-
12	room air conditioning – central air conditioning	N.V PUBLICATION-TEXT BOOK	**https://www.youtube.com/watch?v=hV0UWlQ-oKw**		-
13	loads encountered in air conditioning systems	N.V PUBLICATION-TEXT BOOK	-	PPT	-

Prepared by:S.DIVAKARAN	Verified by:
Submitted by IQAC on:	Checked and Approval by IQAC on:

Sign of IQAC coordinator

Unit – I

Chapter 1. BASICS OF THERMODYNAMICS

1. Introduction

Thermodynamics is a field of science, which deals with the energies possessed by gases and vapours. It also includes the conversion of these energies into heat and mechanical work, and their relationship with properties of the system. A machine which converts heat energy into mechanical work is known as ***heat engine***.

1. Definitions and Units

a) ***Mass (m)* :** Mass is the amount of matter contained in a given body. Mass does not change from place to place. It is expressed by the symbol *'m'*. In SI system, the unit of mass is 'kg'.

a) ***Weight (W)* :** Weight is the amount of force acting on the mass of a body due to gravitational acceleration. Since the gravitational pull varies with the distance of the body from the centre of the earth, therefore weight of the body will also vary with its position on the earth's surface. It is expressed by the symbol *'W'*. In SI system, the unit weight is N (newton) or kN.

a) ***Force (F)***: According to Newton's second law of motion, the applied force is proportional to mass and acceleration. Force is expressed by the symbol *'F'*. In SI system, the unit of force is N (newton) or kN.

Mathematically, Force, $F \propto ma$ or $F = kma$

Where, k is a constant of proportionality

For the sake of convenience, the unit of force adopted is such that it produces a unit acceleration to a body of unit mass i.e. k=1

$\therefore F = ma$ = mass × accelerati on

d) Density (ρ) : The density of a substance is defined as the mass per unit volume of the substance. It is expressed by the symbol 'ρ'. In SI system, the unit of density is ' kg/m^3 '

$$\text{Density, } \rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{V} \; (kg / m^3)$$

Density is also known as *mass density* or *specific mass*. Density of water is 1000 kg/m^3 .

e) Specific weight (w) : Specific weight of a substance is defined as the weight per unit volume of the substance. It is expressed by the symbol *w*. In SI system, the unit of specific weight is N/ m^3

$$\text{Specific weight, } w = \frac{\text{weight}}{\text{volume}} = \frac{W}{V} = \frac{mg}{V} \; (N/ m^3)$$

Specific weight of water is 9810 N/ m^3 .

f) Specific volume (v) : Specific volume of a substance is defined as the volume occupied by unit mass of the substance. It is the reciprocal of density. It is expressed by the symbol *v*. In SI system, the unit of specific volume is m^3 /kg.

$$\text{Specific volume, } v = \frac{\text{volume}}{\text{mass}} = \frac{V}{m} \; (m^3 /kg)$$

g) Specific gravity (s) : Specific gravity of a substance is defined as the ratio of the density (or specific weight) of that substance to the density (or specific weight) of a standard substance. For liquids, water is taken as standard substance . Specific gravity is expressed by the symbol '*s*'. Since it is the ratio of two same quantity, it has no units.

Specific gravity,

$$s = \frac{\text{density (or specific weight) of the given substance}}{\text{density (or specific weight) of the standard substance}}$$

1.3 Pressure

The pressure is defined as the normal force per unit area.

Pressure is expressed by the symbol 'p'.

Pressure, $p = \text{Force}/\text{Area} = \frac{F}{A}$ (N/ m²)

Unit of pressure : The unit of pressure depends upon the units of force and area. In SI system, the practical unit of pressure is N/ m², N/m m², kN/ m², bar, Pascal (pa), etc.

1 Pa = 1 N/ m²; 1 Mpa = 1 $\times 10^6$ N/ m².

1 bar = 1 $\times 10^5$ N/ m²

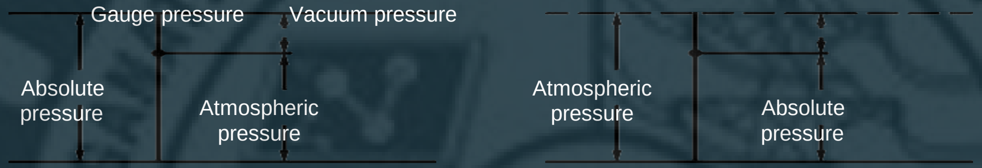


Fig.1.1 Pressure relationship

Atmospheric pressure (p_{atm}) : It is the pressure exerted by the air on the earth's surface. The value of atmospheric pressure at Mean Sea Level is 1.03125 bar or 760 mm height of mercury in a barometer.

Atmospheric pressure, p_{atm} = 1.01325 bar

= 1.01325 $\times 10^5$ N/ m²

= 101.325 kN/ m²

= 760 mm of Hg

=10.34 m of water

Absolute pressure (p_{abs}) : The actual pressure in any system is known as absolute pressure.

Gauge pressure (p_g) : It is the pressure recorded by the pressure gauge. All the pressure gauges read the difference between the actual pressure and the atmospheric pressure.

Absolute pressure = Atmospheric pressure + Gauge pressure $P_{abs} = p_{atm} + p_g$

Vacuum pressure (p_g) : The pressure which is below the atmospheric pressure is known as vacuum pressure or negative pressure. Vacuum gauges are used to record this pressure. In this case,

Absolute pressure = Atmospheric pressure – Vacuum pressure

4. Temperature

Temperature is a thermodynamic property, which determines the degree of hotness or the level of heat intensity of a body. It may also be defined as a measure of velocity of fluid particles. The Temperature of a body is measured by an instrument known as *thermometer*. The commonly used scales for measuring the temperature of a body are :

1. Celsius or centigrade scale
2. Fahrenheit scale

Celsius or centigrade scale : This scale was first used by Celsius in 1742. In this scale, the freezing point of water is taken as zero and the boiling point of water is taken as 100 ^{o}C . The space between these two points has divided into 100 equal divisions and each division represents one degree Celsius.

Fahrenheit scale : In this scale, the freezing point of water is taken as 32°F and the boiling point of water is taken as 212°F. The space between these two points has divided into 180 equal divisions and each division represents one degree Fahrenheit.

The relationship between Celsius scale and Fahrenheit scale is given by ; $C = \frac{5}{9}(F - 32)$

1.5 Absolute temperature

The zero readings of Celsius and Fahrenheit scales are chosen arbitrarily for the purpose of simplicity. But, whenever the value of temperature is used in equations relating to fundamental laws, true zero or absolute zero temperature should be used. *Absolute zero temperature is the temperature below which the temperature of any substance cannot fall.*

The absolute zero temperature is taken as –273 °C in the case of Celsius scale. The temperature measured from this zero temperature is called *absolute temperature*. In Celsius scale, the absolute temperature is called degree *Kelvin (K).* In SI units, degrees Kelvin is not written as °K but only K. ∴K = °C + 273

Note : For thermodynamics calculations, all the temperature values must be converted into Kelvin (K) before substitution in the formula. For example, if the temperature is given as 100 °C , then the absolute temperature = 100 + 273 = **373 K**

6. Standard Temperature and Pressure (S.T.P)

The conditions of temperature and pressure of any gas under standard atmospheric conditions are termed as Standard Temperature and Pressure (S.T.P). S.T.P Values are,

Standard temperature = 15 °C = 288K

Standard pressure = 760 mm of Hg = 101.325 kN/ m^2.

6. Normal Temperature and Pressure (N.T.P)

The conditions of temperature and pressure of any gas under normal atmospheric conditions are termed as Normal Temperature and Pressure (N.T.P). N.T.P Values are,

Normal temperature = 0 °C = 273K

Normal pressure = 760 mm of Hg = 101.325 kN/ m^2.

6. Heat

The heat is defined as the energy transferred across the boundary of a system due to the temperature difference between the system and the surroundings. It is represented by the symbol
Q. In SI system, the unit of heat is **joule** (J) or **kilo-joule** (kJ).

If *m* kg of substance is heated from an initial temperature T_1 to a final temperature T_2, then the heat transfer is given by,

$$Q = m.C.(T_2 - T_1)$$

where, *C* = specific heat of the substance (J/kg.K)

- If *Q* is positive, heat is supplied to the system (heating process)
- If *Q* is negative, heat is rejected from the system (Cooling process)

1.9 Specific heat capacity (C)

The specific heat capacity of a substance is defined as the quantity of heat transfer required to raise or lower the temperature of the unit mass of the substance through one degree. It is represented by the symbol C. In SI system, its unit is given as J/kg.K or kJ/kg.K.

Specific heat capacity at constant volume (C_v): It is defined as the quantity of heat transfer required to raise or lower the temperature of the unit mass of the substance through one degree when the volume remains constant. It is represented by the symbol C_v. When a gas is heated or cooled at constant volume, the heat transfer is given by,

$$Q = m.C_v.(T_2 - T_1) \text{ kJ}$$

where, Q = Heat transferred (kJ) m = Mass of the gas (kg)

C_v = Specific heat capacity at constant volume

T_1 = Initial temperature of the gas (K)

T_2 = Final temperature of the gas (K)

Specific heat capacity at constant pressure (C_p): It is defined as the quantity of heat transfer required to raise or lower the temperature of the unit mass of the substance through one degree when the pressure remains constant. It is represented by the symbol C_p. When a gas is heated or cooled at constant volume, the heat transfer is given by,

$$Q = m.C_p.(T_2 - T_1) \text{ kJ}$$

where, C_p = Specific heat capacity at constant pressure

Note : *C_p is always greater than C_v.* When a gas is heated at constant pressure, the volume of the gas increases. Thus work is done by the gas by expanding. Hence heating in constant pressure gives a higher value for the specific heat than heating in a constant volume.

Adiabatic index (γ): The ratio of the two specific heat capacities remains constant and is called as *adiabatic index*. It is represented by the symbol γ.

Adiabatic index, $\gamma = \frac{C_p}{C_v}$

For air: C_p **=1.005 kJ/kg.K;** C_v **= 0.718 kJ/kg.K; γ=1.4.**

1.10 Work

Work is defined as the product of force (F) and the distance moved (x) in the direction of force. It is represented by the symbol W. In SI system, the unit of work is N-m or joule (J).

Work done by the gas

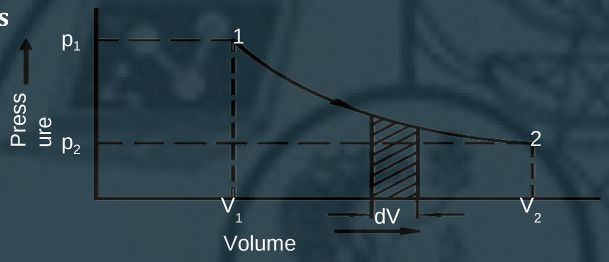


Fig.1.2 Work done by the gas

Consider a piston and cylinder arrangement filled with a gas as shown in the fig. Let the gas expands from state 1 to state 2.

Let, p – Intensity of pressure of the gas on the piston (N/ m^2) A – Area of cross section of the piston (m^2)

Force on the piston, $F = p.A$

Consider a small distance dx moved by the piston. Then the work done by the gas is given by,

dW = Force × distance = $p.A.dx$

$dW = p.dV$ ($A.dx = dV$; Change in volume)

Total work done during the process 1 to 2 is given by,

$$\int_1^2 dW = \int_1^2 p.dV$$

$$W_{1-2} = \int_1^2 p.dV \qquad \text{(N - m)}$$

Hence, for any process, the mechanical work done is given by,

$$\boldsymbol{W = \int_1^2 p.dV} \qquad \textbf{(N - m or J)}$$

- If *W* is positive, work is done by the system (gas) and the process is called expansion process
- If *W* is negative, work is done on the system (gas) and the process is called compression process.

11. Power

Power may be defined as the rate of doing work or work done per unit time. It is represented by the symbol *P*. In SI system, the unit of power is Watts (W).

1 W = 1 J/s = 1 N-m/s 1 kN-m/s = 1kJ/s = 1 kW

1 kW-s = 1 kJ; 1 kW-hr = 3600 kJ.

11. Thermodynamic system, boundary and surroundings

System : The thermodynamic system may be defined as a definite area or a space where some thermodynamic process is taking place.

Surroundings : Anything outside the boundaries which affects the behaviour of the system is known as surroundings.

Boundaries : The system and the surroundings are separated by the system boundary. The system boundary may be real or imaginary.

11. Types of thermodynamic systems

Thermodynamic systems may be classified as follows:

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

1. Closed system

A closed system permits the transfer of heat and work across its boundaries; but it does not permit the transfer of mass. The mass of the working substance in a closed system remains constant. The system boundary is determined by the space occupied by the working substance.

Example :

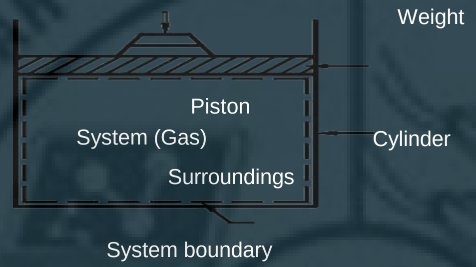


Fig.1.3 Closed thermodynamic system

The piston and cylinder arrangement shown in the figure is an example of closed system. The gas in the cylinder is considered as system. If the heat is supplied to the cylinder, the temperature of the gas will increase and the piston will move.

As the piston moves, the boundary of the system moves. In other words, the heat and work energy crosses the boundary of the system during this process, but there is no addition or loss of the original mass of the working substance.

2. Open system

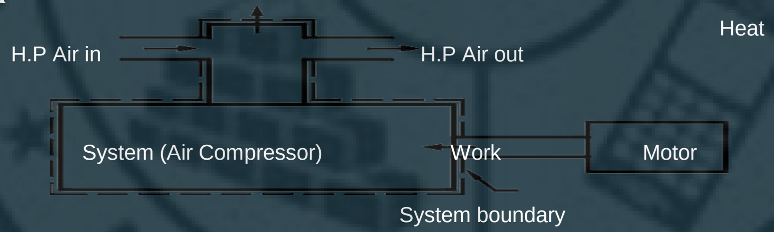


Fig.1.4 Open thermodynamic system

In this system, the mass of the working substance crosses the boundary of the system. Heat and work may also cross the boundary. The mass within the system may not be constant during the process. An open system may be called as *control volume*.

Example :

The compressor unit shown in the figure is an example of open system. In this system, the low pressure air enters the compressor and leaves the high pressure air. Thus the mass of working substance crosses the boundary of the system. The work crosses the boundary of the system through the driving shaft and the heat is transferred across the boundary from the cylinder walls.

3. Isolated system

A system which is not influenced by the surroundings is called an isolated system. In an isolated system, there is no mass, heat or work transfer takes place. This is an imaginary system.

Example : An open system with an universe as its surrounding is an example of an isolated system.

1.14 State of a system

The state of a system is the condition of the system at any particular moment which can be identified by the statement of its properties. The number of properties required to describe a system depends upon the nature of the system.

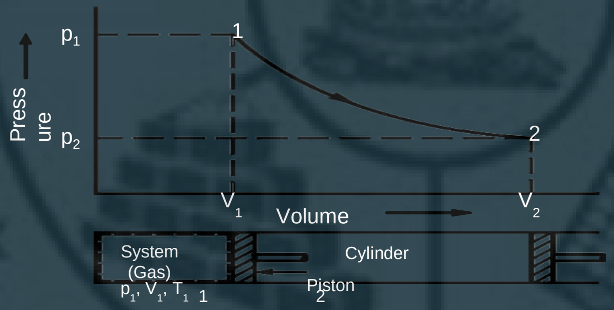


Fig.1.5 State of a system

Consider a system (gas) enclosed in a cylinder and piston arrangement as shown in the figure. Let the equilibrium state of the piston at position 1 is represented by its properties p_1, V_1, and T_1. When the system expands, the piston moves towards right and occupies the final position 2. The final equilibrium state is represented by the properties p_2, V_2, and T_2. The pressure-volume (*p*-*V*) diagram indicating the initial and final states is also shown in the figure.

1.15 Properties of a system

The quantities, which identify the state of a system, are called *properties*. The thermodynamic properties of a system may be classified as

a) Extensive properties b) Intensive properties.

a) ***Extensive properties :*** The properties of system, whose value for the entire system is equal to the sum of their values for the individual parts of the system, are called extensive properties. These are dependent on the mass of the system.

Example : Total volume, total energy, total mass, etc.

b) ***Intensive properties :*** The properties which are independent on mass of the system. These properties remain same in all individual parts of the system.

Example : Temperature, pressure, specific volume, etc.

1.16 Thermodynamic process

Thermodynamic process is a path of change in state of a system from one equilibrium state to another equilibrium state. The different thermodynamic processes are:

- Constant volume process
- Constant pressure process
- Constant temperature process
- Isentropic or reversible adiabatic process
- Polytropic process
- Hyperbolic processFree expansion process
- Throttling process

1.17 Thermodynamic cycle or cyclic process

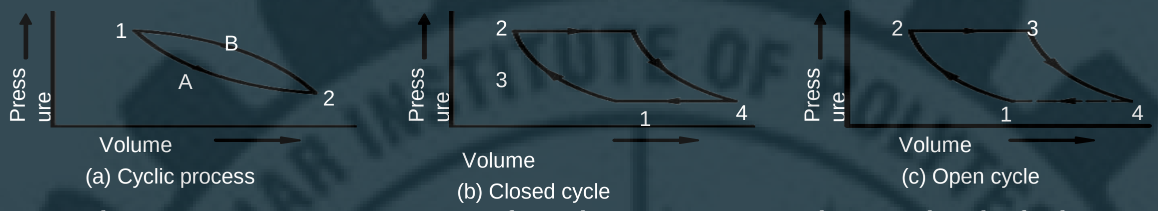


Fig.1.6 Cyclic process

When a process or processes are performed on a system in such a way that the final state is identical with the initial state, then it is said to be thermodynamic cycle of cyclic process.

In fig.(a), 1-A-1 and 2-B-1 are processes whereas 1-A-2-B-1 is a thermodynamic cycle or cyclic process

Thermodynamic cycle may be classified as

(a) Closed cycle and (b) Open cycle

(a) ***Closed cycle :*** In a closed cycle system, the working substance is recirculated again and again in the system. Fig.(b) represents the closed cycle system gas turbine plant.

(b) ***Open cycle :*** In an open cycle system, the working substance is exhausted to atmosphere after expansion. Fig.(c) represents an open cycle gas turbine plant.

1.18 Point function and path functions

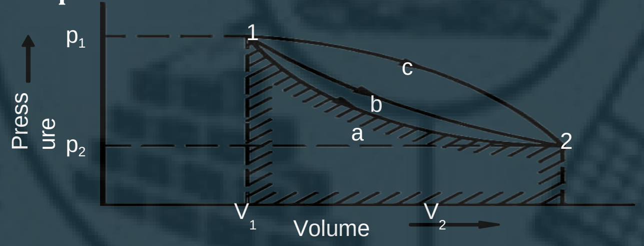


Fig.1.7 Point and path functions

Point function : A function, whose value is independent of the path followed by the system, is known as point function. The values depend only on the initial and final state of the system. Thermodynamic properties are point functions, since for a given state, there is a definite value for each property.

Example : Pressure, temperature, volume, etc.

Path function : A function, whose value depends on the path followed by the system, is known as path function.

Example : Work done, heat transfer, etc.

Consider a system undergoing a change of state from state 1 to state 2.

Let, p_1, V_1 = Pressure and volume of system at state 1

p_2, V_2 = Pressure and volume of system at state 2 Change in pressure, $dp = p_2 - p_1$

Change in volume, $dV = V_2 - V_1$

The change of state from 1 to 2 may be carried out through a number of paths such as *1-a-2, 1-b-2, 1-c-2,* etc. It can be noticed that the change in pressure or change in volume is the same irrespective of the path followed by the system. Therefore, these properties are point functions.

Work done during the process *1-a-2* = Area *1-a-2-* V_2 - V_1 *-1*

Work done during the process *1-b-2* = Area *1-b-2-* V_2 - V_1 *-1*

Work done during the process *1-c-2* = Area *1-c-2-* V_2 - V_1 *-1*

Thus the work done during a process depends on the paths followed by the system. So, it is a path function.

1.19 Energy

The energy is defined as the capacity to do work. A system possesses the following two types of energies:

a) Stored energy b) Transit energy (or energy in transition)

a) Stored energy : it is the energy possessed by a system within its boundaries. The potential energy, kinetic energy and internal energy are the example of stored energy.

Potential energy : it is the energy possessed by a system by virtue of its position above the ground level

Potential energy, $PE = mgz$

where, m = mass of the system

g = Acceleration due to gravity

z = Height of the system above the ground level

Kinetic energy : It is the energy possessed by a system, by virtue of its mass and velocity of motion.

Kinetic energy, $KE = \frac{1}{2} mv^2$

where, v = Velocity of the system.

Internal energy : It is the energy possessed by a body or a system due to its molecular arrangement and motion of the molecules. It is generally represented by U.

b) Transit energy or energy in transition : It is the energy possessed by a system which is capable of crossing boundaries. The heat, work and electrical energy are the examples of transit energy.

20. Law of conservation of energy

It states that, energy can neither be created nor destroyed, but it can be transferred from one form to another form i.e. the total energy in any system remains constant.

In thermodynamics, it states that, the total heat transferred in a system must be equal to the sum of the external work done and the change in internal energy.

Heat transfer = Work done + Change in internal energy

$$Q = W + \Delta U$$

20. Thermodynamic equilibrium

A system is said to be in equilibrium, if it does not tend to undergo any change of state on its own accord. Any further change must be produced only by external means.

Consider a system undergoes a change of state from state 1 to state 2. This law when applied to this process,

$$U_1 + Q = U_2 + W$$

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

where, Q = Heat transferred
W = Work done
ΔU = Change in internal energy

1.24 Correlation of First law of thermodynamics

1. Perpetual Motion Machine (PMM) of the first kind is impossible

A perpetual motion machine (PMM) of the first kind is an imaginary machine which delivers work continuously without any heat input. In this case,

$Q = 0$; $\therefore W$ must be equal to zero.

But PMM of the first kind delivers work continuously which is impossible. It creates energy without any input and thus violates the first law of thermodynamics. Hence a perpetual motion machine of the first kind is impossible.

2.If a closed system is isolated from its surroundings, there is no change in internal energy of the system.

For the isolated system, $Q = 0$ and $W = 0$
By first law of thermodynamics, $Q = W + \Delta U$

$$0 = 0 + \Delta U$$

$$\Delta U = 0 \text{ i.e. } \boldsymbol{U_2 = U_1}$$

1.28 Second law of thermodynamics

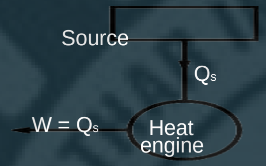
The second law of thermodynamics may be defined in many ways. The two common statements are Kelvin-Planck statement and Clausius statement.

Kelvin-Planck statement

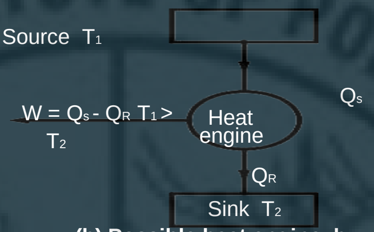
(i) It is impossible to construct a heat engine working on cyclic process, whose only purpose is to convert all the heat energy supplied to it into an equal amount of work

(ii) No heat engine which is working on cyclic process can convert more than a small fraction of the heat energy supplied to it into useful work. A large part of it is necessarily rejected as heat.

Explanation :



(a) Impossible heat engine by second law



(b) Possible heat engine by second law

Fig.1.9 Kelvin-Planck statement

Figure shows a heat engine working on a cyclic process. It receives heat (Q_s) from a heat source and delivers work (W) equal to heat received. By second law of thermodynamics, all the heat received cannot be converted into useful work and a part of heat received is to be rejected to a low temperature reservoir (sink). Hence a heat engine should have two heat reservoirs at different temperatures for converting continuously heat energy into useful work.

Clausius statement

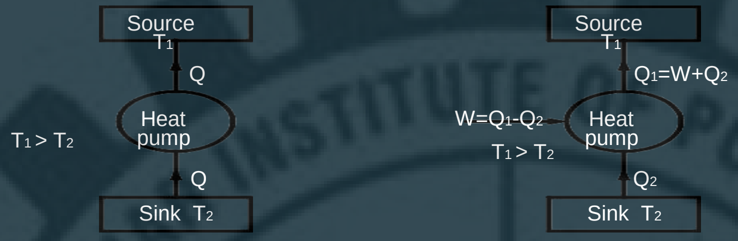
(i) Heat can flow from a hot body to a cold body without any assistance. But heat cannot flow from a cold body to a hot body without any external work.

(or)

(ii) It is impossible to construct a machine working on a cyclic process whose only purpose is to transfer heat from a cold body to a hot body.

Explanation :

Consider a heat source at higher temperature T_1 and a heat sink at a lower temperature T_2. By Clausius statement heat cannot flow from the sink to heat source without any external work.



(a) Impossible system **(b) Possible system**

Fig.1.10 Clausius statement

But heat can flow from sink to the source with the help of an external work through a device such as heat pump.

1.29 Combination of Kelvin-Planck and Clausius statement

Consider a system consisting of a heat engine and heat pump working in the same temperature range as shown in the figure.

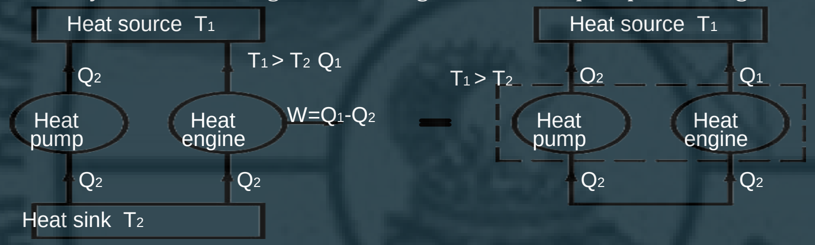


Fig.1.11 Equivalence of Kelvin-Planck and Clausius statement

The heat engine receives heat Q_1 from the source and rejects heat Q_2 to the heat sink and develops a net work W. The net work done is given by, $W = Q_1 - Q_2$. This follows Kelvin-Planck statement.

The heat pump transfers heat Q_2 from the low temperature sink to high temperature source without any work input. This violates the Clausius statement.

The heat engine and the heat pump can be combined by eliminating the sink. The heat rejected by the engine (Q_2) is taken by the pump. The equivalent system is shown in fig.(b). This system acts an engine transferring heat from only one reservoir and converting it into equivalent amount of work. This violates Kelvin-Planck statement.

Hence violation of Clausius statement also violates Kelvin- Planck statement.

Consider another system as shown in fig.(a). The heat engine receives a heat of Q_1 from the source and converts in into equivalent amount of work W. This violates Kelvin-Planck statement.

Heat pump transfers a heat of Q_2 from the sink and supplies a heat of $Q_2 + W$ to the source. It receives a work of W from the heat engine. It is not contrary to Clausius statement.

An equivalent system for this is shown fig. (b). This system transfers heat Q_2 from the sink at the lower temperature to the source at higher temperature without the aid of external work. This violates the Clausius statement.

From the above examples, we can understand that both Kelvin-Planck and Clausius statement of second law or thermodynamics are same. Violation of one statement will violates the other statement.

1.30 Perpetual Motion Machine (PMM) of the second kind

A *perpetual motion machine (PMM) of the second kind* receives heat continuously from a single reservoir and converts it into equivalent amount of work. Thus it gives 100% efficiency. This violates the second law of thermodynamics. Hence a PMM of the second kind is impossible to construct.

31. Perfect gases

A perfect gas may be defined as a state of substance, whose evaporation from its liquid state is complete, and strictly obey gas laws under all conditions of temperature and pressures. In actual practice, there is no gas which strictly obeys the gas laws over the entire range of temperature and pressure. But the real gases which are ordinarily difficult to liquefy, such as oxygen, nitrogen, hydrogen and air may be considered as perfect gases within certain temperature and pressure limits.

31. Laws of perfect gases

The behaviour of perfect gas is governed by the following gas laws:

- Boyle's law
- Charles's law
- Joule's law
- Regnault's law
- Avagadro's law

a) Boyle's law

Boyle's law states that, the absolute pressure of a given mass of a perfect gas is inversely proportional to its volume, when the temperature remains constant.

Mathematically, $p \propto \frac{1}{V}$ or $pV = \text{Constant}$

i.e. $\boldsymbol{p_1 V_1 = p_2 V_2 = C}$

where, p_1 = Original pressure of the gas (N/ m^2)

V_1 = Original volume of the gas (m^3)

p_2 = Final pressure of the gas after change of state (N/ m^2)

V_2 = Final volume of the gas after change of state (m^3)

$T_1 = T_2 = T$ = Constant temperature of the gas

b) Charles's law

Charles's law states that, the volume of a given mass of perfect gas is directly proportional to its absolute temperature, when the pressure remains constant.

Mathematically, $V \propto T$ (or) $\frac{V}{T}$ = Constant

i.e. $\frac{V_1}{T_1} = \frac{V_2}{T_2} = C$

c) Gay-Lussac law

Gay-Lussac law states that, the absolute pressure of a given mass of perfect gas is directly proportional to its absolute temperature, when the volume of the gas remains constant.

Mathematically, $p \propto T$ (or) $\frac{p}{T}$ = Constant

i.e. $\frac{p_1}{T_1} = \frac{p_2}{T_2} = C$

d) Joule's law

Joule's law states that, the change of internal energy of a perfect gas is directly proportional to the change in temperature. Mathematically, $dE \propto dT$

(or) $dE = m.C.dT = m.C(T_2 - T_1)$

where, m = Mass of the gas

C = A constant of proportionality, known as specific heat.

e) Regnault's law Regnault's law states that, the two specific heats C_p and C_v of a perfect gas do not change with the change in temperature, i.e. C_p and C_v of a gas always remain constant.

f) Avagadro's law

It states that, equal volumes of all gases, at the same temperature and pressure, contain equal number of molecules.

Mathematically, $M.v$ = Constant

where, M = Molecular weight of the gas

v = Specific volume of the gas.

$M.v$ is known as molar volume and it is represented as V_{mole}. The molar volume of any gas at N.T.P [^oC and 1.01325 bar] is given by V_{mole} = 22.4 m^3 / kg.mole

1.32 General gas equation

The general gas equation can be obtained by combining Boyle's law and Charles's law.

According to Boyle's law, $p \propto \frac{1}{V}$ (or) $V \propto \frac{1}{p}$ .... (1)

According to Charles's law, $V \propto T$ .... (2)

Combining (1) and (2) $V \propto \frac{1}{p}$ and T (or) $V \propto \frac{T}{p}$

i.e. $pV \propto T$ (or) $pV = CT$

The more useful form of general gas equation is

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = Constant$$

1.33 Characteristic equation of gas

It is the modified form of general gas equation. If the volume (V) in the general gas equation is replaced by specific volume (v), then the constant C is represented by another constant R.

Thus the general gas equation becomes, $pv = RT$

where, R = Characteristic gas constant or gas constant.

For any mass m kg of gas, the characteristic equation becomes,

The unit of gas constant R may be obtained as follows:

$$R = \frac{pV}{mT} = \frac{\frac{N}{m^2} \times m^3}{kg \times K} = \frac{N - m}{kg \times K} = J/kg.K$$

In SI units, the value of R for air = 287 J/kg.K = 0.287 kJ/kg.K

1.34 Universal gas constant (R_{mole})

The product of molecular weight (M) and the characteristic gas constant (R) is same for all gases. This constant is known as universal gas constant. It is expressed as R_{mole} or R_u.

$M.R = R_{mole} = R_u$

By characteristic gas equation, $p.v = R.T$ (v = specific volume)

Multiplying both sides by M (Molecular weight),

$p.M.v = M.R.T$

$\boldsymbol{p.V_{mole} = R_{mole}.T}$ [∵ $\boldsymbol{M.v = V_{mole}}$; $\boldsymbol{M.R = R_{mole}}$]

The above equation is known as *universal gas equation.* The value of R_{mole} is same for all gases since V_{mole} is same for all gases at any given pressure and temperature.

$$R_{mole} = \frac{p.V_{mole}}{T} = \frac{101.325 \times 22.4}{273} = 8.314 \text{ kJ/kg.mole.K}$$

At N.T.P conditions, ∴ $R_{mole} = R_u = 8314$ J/kg.mole.K

1.35 Relationship between C_p and C_v

Consider a gas heated at constant pressure.

Let, p_1, V_1, T_1 = Initial pressure, volume and temperature of the gas respectively.

p_2, V_2, T_2 = Final pressure, volume and temperature of the gas respectively.

C_p = Specific heat of the gas at constant pressure

C_v = Specific heat of the gas at constant volume

m = mass of the gas

By first law of thermodynamics,

$Q = W + \Delta U$ ..... (1)

$Q = mC_p(T_2 - T_1)$ ..... (2)

$W = p.dV = p(V_2 - V_1) = p_2V_2 - p_1V_1 = mR(T_2 - T_1)$ ..... (3)

$\Delta U = mC_v(T_2 - T_1)$ ..... (4)

Substitute (2), (3) and (4) in (1)

$mC_p(T_2 - T_1) = mR(T_2 - T_1) + mC_v(T_2 - T_1)$

Dividing throughout by $m(T_2 - T_1)$

$C_p = R + C_v$

Unit – I Chapter 2. THERMODYNAMIC PROCESSES OF PERFECT GASES

Introduction

When a system changes its state from one equilibrium state to another equilibrium state, then the path of successive states through which the system is passed, is known as thermodynamic process. If the process is assumed to take place sufficiently slow so that the properties in the intermediate states are in equilibrium state, then the process is called quasi−static or reversible process. If the process takes place in a such a manner that the properties at the intermediate state are not in equilibrium state, then the process is said to be non−equilibrium or irreversibel process.

The different thermodynamic processes include the following:

1. Constant volume (Iso−choric) process
2. Constant pressure (Iso−baric) process
3. Constant temperature (Iso−thermal) process
4. Hyperbolic process
5. Reversible adiabatic (Isentropic) process
6. Polytropic process
7. Free expansion process
8. Throttling process

The following notations are used in this chapter.

p_1 = Initial pressure of the gas (N/m^2)

V_1 = Initial volume of the gas (m^3)

T_1 = Initial temperature of the gas (K)

H_1 = Initial enthalpy of the gas (kJ)

U_1 = Initial internal energy of th egas (kJ)

S_1 = Initial entropy of the gas (kJ/kg)

p_2 = Final pressure of the gas (N/m^2)

V_2 = Final volume of the gas (m^3)

T_2 = Final temperature of the gas (K)

H_2 = Final enthalpy of the gas (kJ)

U_2 = Final internal energy of th egas (kJ)

S_2 = Final entropy of the gas (kJ/kg)

C_p = Specific heat at constant pressure (kJ/kg.K)

γ = Ratio of specific heats

C_v = Specific heat at constant volume (kJ/kg.K)

2.2 Change in internal energy during a process (ΔU)

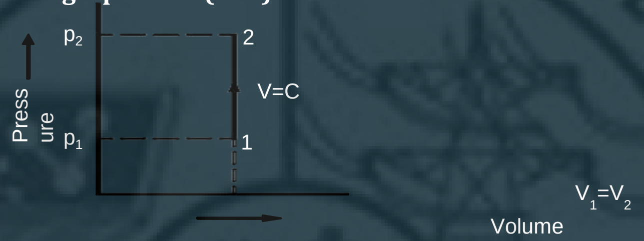


Fig.2.1 Constant volume heating

Consider a system (gas) as shown in figure, which is to be heated at constant volume from state 1 to state 2.

p_1, V_1, T_1 = Initial pressure, volume and temperature of the gas respectively before heating.

p_2, V_2, T_2 = Final pressure, volume and temperature of the gas respectively after heating.

By first law of thermodynamics, $Q = W + \Delta U$

$$W = \int_1^2 p.dV = 0 \quad [\because \text{ There is no change in volume , i.e. } dV = 0]$$

$$\therefore Q = 0 + \Delta U = m.C_v.(T_2 - T_1)$$

$$\text{(or)} \quad \Delta U = m.C_v.(T_2 - T_1) \text{ .... (1)}$$

Mathematically, change in internal energy, $\Delta U = m.C_v.\int_1^2 dT$

For unit mass, $\Delta u = C_v.(T_2 - T_1) = C_v.dT$

The equation (1) can be used for all the processes of a perfect gas between the temperature range T_1 to T_2.

3. Enthalpy

Enthalpy is the sum of the internal energy and the product of pressure and volume ($p.V$). It is represented by the symbol H.

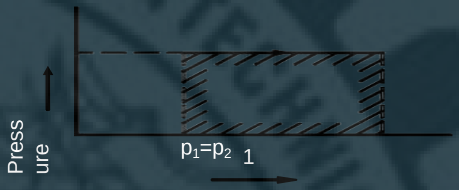
Mathematically, enthalpy, $\boldsymbol{H = U + p.V}$

Since ($U + p.V$) is made up of properties, enthalpy (H) is also a property. For unit mass, specific enthalpy, $h = u + p.v$

where, u = specific internal energy

v = specific volume

3. Change in enthalpy during a process (ΔH)



g.2.2 Constant pressure heating

Consider a system (gas) as shown in figure, which is to be heated at constant pressure from state 1 to state 2.

p_1, V_1, T_1 = Initial pressure, volume and temperature of the gas respectively before heating.

p_2, V_2, T_2 = Final pressure, volume and temperature of the gas respectively after heating.

By first law of thermodynamics, $Q = W + \Delta U$ .....(1)

$$W = \int_1^2 p.dV = p\int_1^2 dV \quad [\because p = \text{constant}]$$

$$W = p.[V]_1^2 = p.(V_2 - V_1) = p_2.V_2 - p_1.V_1 \quad \text{..... (2)}$$

$$\Delta U = U_2 - U_1 \quad \text{..... (3)}$$

Substituting (2) and (3) in (1)

$$Q = W + \Delta U = p_2.V_2 - p_1.V_1 + U_2 - U_1$$

$$Q = (U_2 + p_2.V_2) - (U_1 + p_1.V_1)$$

$$Q = H_2 - H_1 = \Delta H = \text{Change in enthalpy} \quad \text{..... (4)}$$

The equation (4) can be used for all the processes of a perfect gas between the temperature range T_1 to T_2.

$$\therefore \ \boldsymbol{\Delta H = Q = m.C_p\,(T_2 - T_1)}$$

5. Entropy (*S*)

Entropy is defined as a function of quantity of heat with respect to temperature. Entropy of a substance increases when heat is supplied to it and decreases when heat is rejected from it. Entropy is a form of unavailable energy. It is represented by the symbol *S*.

5. Change in entropy (*dS*)

In a reversible process, the increase or decrease of entropy, when multiplied by the absolute temperature gives the heat absorbed by the working substance.

Mathematically, $dQ = T.dS$

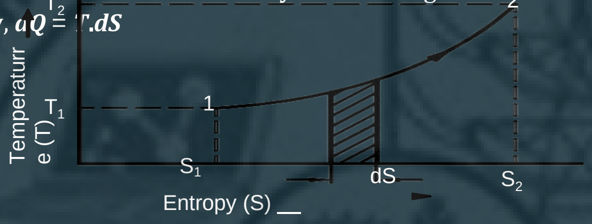


Fig.2.3 T–S diagram

Consider a gas which is heated from state 1 to state 2. There is a change in entropy of the gas. If we consider a small amount of heat addition *dQ* to the gas at an absolute temperature *T*, then change in entropy is given by,

$$dS = \frac{dQ}{T}$$

This heating process can be plotted on a graph, by taking entropy in *x*–axis and absolute temperature in *y*–axis. This graph is known as temperature – entropy (T–S) diagram. The area under the curve in T–S diagram gives the heat transfer during the process.

As shown in the figure, consider an elemental strip of width '*dS*'. Area of elemental strip = Heat transfer through the strip

$$T.dS = dQ \quad \text{(or)} \quad dS = \frac{dQ}{T}$$

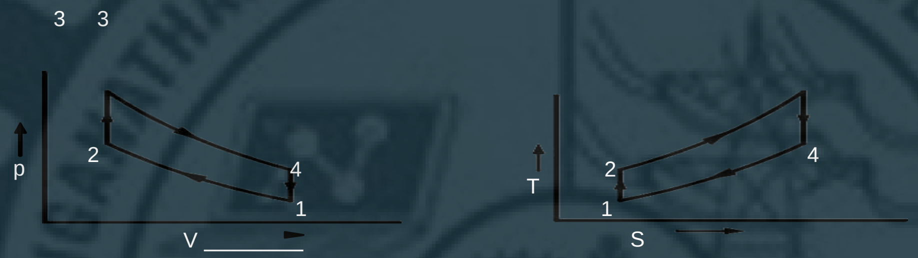
Change in entropy during the process 1–2 is given by,

$$\int_1^2 dS = \int_1^2 \frac{dQ}{T}$$

Unit – II THERMODYNAMIC AIR CYCLES

3.1 Introduction

A thermodynamic cycle consists of a series of thermodynamic operations, which takes place in a certain order, and the initial conditions are restored at the end of the process. These processes can be plotted on p−V diagram and T−S diagram. Each process is represented by its own curve and thus form a closed figure.



(a) p-V diagram (b) T-S diagram

Fig.3.1 Thermodynamic cycle

The area enclosed by the complete curve in the p−V diagram gives the work done during the complete cycle. The net heat transfer during the complete cycle is given by the are enclosed by the complete curve in T−S diagram.

3.2 Air cycles and air standard efficiency

In air cycles, the air is used as the working fluid. The air in an engine cylinder may be subjected to series of operations which cause the air to return to its original state. This is called as air cycle. The thermal efficiency obtained using air as working fluid is known as air standard efficiency. This efficiency is the standard efficiency for all cycles. It is used to compare the performance of engines working on various cycles.

3.3 Efficiencies of cycles

Thermal efficiency

During a cyclic process, a certain quantity of heat is taken by the engine. A portion of this heat is converted into useful work and the remaining heat is rejected. Therefore, work done during the cycle is given by,

Work done, W = Heat supplied − Heat rejected

$$W = Q_s - Q_w$$

Efficiency of the cycle is given by,

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Work done}}{\text{Heatsupplied}} = \frac{\text{Heatsupplied- Heat rejected}}{\text{Heatsupplied}}$$

$$\eta = \frac{W}{Q_s} = \frac{Q_s - Q_r}{Q_s}$$

This efficiency is the theoretical efficiency and is known as thermal efficiency of the cycle. In this efficiency, the practical losses which may occur during the running of an engine are not considered. Hence, the actual thermal efficiency is always less than the theoretical thermal efficiency.

Relative efficiency

The relative efficiency is defined as the ratio of actual thermal efficiency and theoretical thermal efficiency. It is also called as efficiency ratio.

Relative efficiency (or) Efficiency ratio = $\dfrac{\textbf{Actual thermal efficiency}}{\textbf{Theoretica l (ideal) therami efficiency (or) Air standard efficiency}}$

Indicated thermal efficiency (or)

3.4 Reversible and irreversible cycle

Reversible cycle

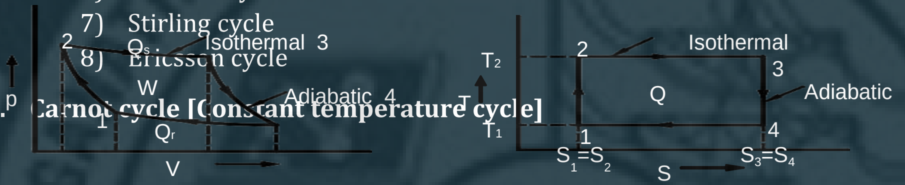
A thermodynamic process is said to be reversible, if the system and surroundings are completely restored back to their initial state when the process reversed.

8. Thermodynamic cycles

The following are the important thermodynamic cycles

1) Carnot cycle [constant temperature cycle]
2) Otto cycle [constant volume cycle]
3) Diesel cycle
4) Joule or Brayton cycle [constant pressure cycle]
5) Dual combustion cycle
6) Rankine cycle
7) Stirling cycle
8) Ericsson cycle

8. Carnot cycle [Constant temperature cycle]



(a) p-V diagram (b) T-S diagram

Fig.3.3 Carnot cycle

This cycle was introduced by Nicolas Leonard Sadi Carnot. It consists of two isothermal processes and two isentropic (reversible adiabatic) processes. The p−V and T−S diagrams of this cycle are shown in the figure.

Working of the cycle

At point 2, the clearance volume of the cylinder is occupied by compressed air. A hot object is placed at the end of cylinder head and the heat is supplied to the air at constant temperature (T_2).

The air expands and forces the piston forward by doing work on the piston. At point 3, the hot object is removed and the air expands isentropically till the temperature falls to T_1 at point 4. The piston reverses and compression stroke starts. A cold object is placed at the end of the cylinder head and the air is cooled at constant temperature (T_1) up to point 1. At point 1, the cold object removed and the air is compressed adiabatically (isentropically) till it returns to its original state 2.

Heat supplied during the constant temperature process 2−3,

$$Q_s = T_2.dS \qquad \left[\because dS = \frac{dQ}{T}\right]$$

Heat rejected during the constant temperature process 4−1,

$$Q_r = T_1.dS$$

Work done during the cycle, $W = Q_s - Q_r = T_2.dS - T_1.dS$ $\quad W = (T_2 - T_1).dS$

Efficiency of the cycle, $\eta_{carnot} = \frac{W}{Q_s} = \frac{(T_2 - T_1).dS}{T_2.dS}$

$$\eta_{carnot} = \frac{(T_2 - T_1)}{T_2} = 1 - \frac{T_1}{T_2}$$

where, T_1 = Minimum temperature of the cycle,
T_2 = Maximum temperature of the cycle

For the two given temperature limits, only Carnot cycle gives the maximum possible efficiency. But, an engine working on Carnot cycle is not possible because of the following reasons:

- For isothermal compression, the piston should move very slowly and for isentropic compression, the piston should move as fast as possible. This speed variation during the same stroke of the piston is not possible.
- It is not possible to provide a heat source which will supply heat without change in temperature.
- It is not possible to avoid friction between moving parts completely.

3.10 Reversed Carnot cycle

The p−*V* and T−S diagram for a reversed Carnot cycle is shown in the figure.

Working of the cycle

1−2 : Isentropic compression in a compressor

2−3 : Isothermal heat rejection to a hot body ($T_2 = T_3$)

3−4 : Isentropic expansion in expansion valve

4−1 : Isothermal heat extraction from a cold body ($T_1 = T_4$)

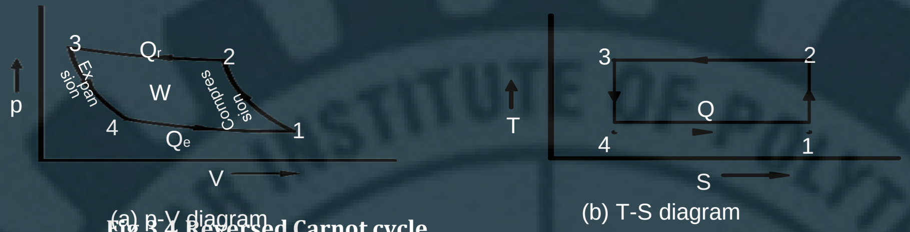


Fig.3.4 Reversed Carnot cycle

Heat is extracted during the isothermal process 4−1.

Heat extracted, $Q_e = T_1.dS$

Heat is rejected during the isothermal process 2−3 Heat rejected, $Q_r = T_2.dS$

Work input, $W = Q_r - Q_e = T_2.dS - T_1.dS = (T_2 - T_1).dS$

The main purpose of Carnot cycle is to extract heat from a cold body and reject heat to a hot body. In this case, the performance of cycle is called as Coefficient of Performance (COP).

In the case of refrigerator, we require a cooling effect. So, COP is defined as the ratio of heat rejected to work input.

$$COP_{ref} = \frac{\text{Heat extracted}}{\text{Work input}} = \frac{Q_e}{W} = \frac{T_1.dS}{(T_2 - T_1).dS}$$

$$\therefore \boldsymbol{COP_{ref} = \frac{T_1}{T_2 - T_1}}$$

In the case of heat pump, heating effect is required. So, COP is defined as the ratio of heat delivered to the work input.

$$COP_{hp} = \frac{\text{Heat rejected}}{\text{Work input}} = \frac{Q_r}{W} = \frac{T_2.dS}{(T_2 - T_1).dS}$$

$$\therefore \boldsymbol{COP_{hp} = \frac{T_2}{T_2 - T_1}}$$

3.11 Otto cycle or Constant volume cycle

The first successful engine working on this cycle was introduced by Nicholas A. Otto in 1876. Nowadays, many gas, petrol and many of the oil engines run on this cycle. Since, the heat is supplied and rejected at a constant volume, it is also known as constant volume cycle.

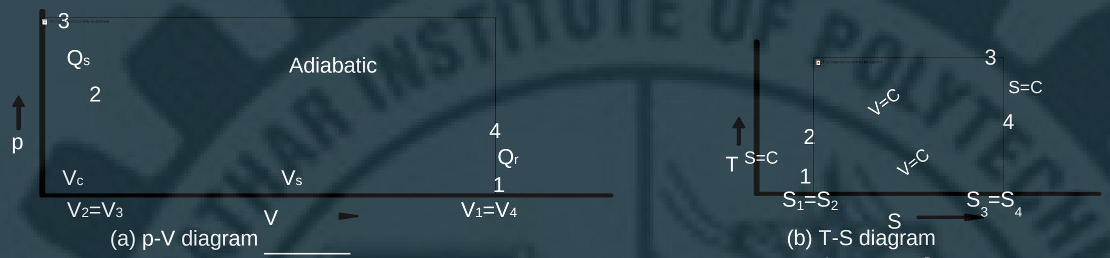


Fig.3.5 Otto cycle

The ideal p−*V* diagram and T−S diagram of this cycle are shown in the figure. It consists of two reversible adiabatic (isentropic) processes and two constant volume processes.

Working of Otto cycle

1−2 : Isentropic compression of air : Pressure and temperature increases. Volume decreases. Entropy remains constant ($S_1 = S_2$)

2−3 : Constant volume heating of air : Pressure, temperature and entropy increases. Volume remains constant ($V_1 = V_2$)

3−4 : isentropic expansion of air : Pressure and temperature decreases. Volume increases. Entropy remains constant ($S_3 = S_4$) *4−1 : Constant volume heat rejection from air:* Pressure, temperature and entropy decreases. Volume remains constant ($V_4 = V_1$)

Heat is supplied at constant volume during the process 2−3 :

∴ Heat supplied, $Q_s = m.C_v.(T_3 - T_2)$

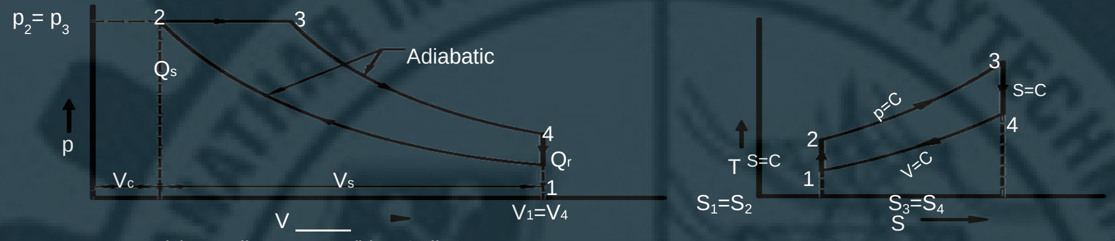
Heat is rejected at constant volume during the process 4−1 :

∴ Heat rejected, $Q_r = m.C_v.(T_4 - T_1)$

Work done, $W = Q_s - Q_r = m.C_v.(T_3 - T_2) - m.C_v.(T_4 - T_1)$

3.13 Diesel cycle

Diesel cycle was introduced by Rudolph Diesel. This cycle is mostly used in diesel engines. It consists of two adiabatic processes, one constant volume process and one constant pressure process. The p−V diagram and T−S diagram for this cycle are shown in the figure.



(a) p-V diagram (b) T-S diagram

Fig. 3.7 Diesel cycle

Working of the cycle

1−2: Air is compressed isentropically $(S_1 = S_2)$

2−3: Air is heated at constant pressure $(p_2 = p_3)$*. Heat supply is stopped when temperature reaches to* T_3 *at point 3. This point 3 is known as cut−off point. The volume at this point* (V_3) *is known as cut−off volume.*

3−4: Air is expanded isentropically $(S_3 = S_4)$

4−1: Air is cooled at constant volume $(V_4 = V_1)$

Heat is supplied during constant pressure process 2−3 Heat supplied, $Q_s = m.C_p.(T_3 - T_2)$

Heat is rejected during constant volume process 4−1 Heat rejected, $Q_r = m.C_v.(T_4 - T_1)$

Efficiency, $\eta_{diesel} = \frac{W}{Q_s} = \frac{m.C_p.(T_3 - T_2) - m.C_v.(T_4 - T_1)}{m.C_p.(T_3 - T_2)}$

Work done during the cycle, $W = Q_s - Q_r$

$W = m.C_p.(T_3 - T_2) - m.C_v.(T_4 - T_1)$

$$\eta_{diesel} = 1 - \frac{1}{\gamma}\left[\frac{T_4 - T_1}{T_3 - T_2}\right] \qquad \left[\frac{C_p}{C_v} = \gamma\right]$$

The above efficiency equation can be simplified in terms of volume ratios as follows.

Cut−off ratio is defined as the ratio of volume at point of cut−off to the clearance volume.

Cut−off ratio, $\rho = \frac{\text{Cut - off volume}}{\text{Clearance volume}} = \frac{V_3}{V_c} = \frac{V_3}{V_2}$

Compression ratio, $r = \frac{\text{Total cylinder volume}}{\text{Clearance volume}} = \frac{V_1}{V_2}$

Adiabatic expansion ratio $= \frac{V_4}{V_3} = \frac{V_1}{V_3} = \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} = r \cdot \frac{1}{\rho} = \frac{r}{\rho}$

Consider the isentropic compression 1−2:

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

Consider constant pressure process 2−3

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}; \quad \frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho; \quad \therefore T_3 = T_2 \cdot \rho = T_1 \cdot (r)^{\gamma-1} \cdot \rho$$

Consider adiabatic expansion 3−4

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{r}{\rho}\right)^{\gamma-1}; \quad \therefore T_4 = \frac{T_3}{\left(\frac{r}{\rho}\right)^{\gamma-1}} = \frac{T_1 \cdot (r)^{\gamma-1} \cdot \rho \cdot \rho^{\gamma-1}}{(r)^{\gamma-1}}$$

$$\therefore T_4 = T_1 \cdot \rho^{\gamma}$$

Substitute the values of T_2, T_3 and T_4 in efficiency equation,

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

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

From the above equation, it is understood that

a) If compression ratio (r) increases, the efficiency of diesel cycle increases.

b) If cut−off ratio (ρ) increases, the efficiency of diesel cycle decreases.

Unit – II Chapter 2. HEAT TRANSFER

1. Heat transfer

Heat is defined as the transfer of thermal energy across a well-defined boundary around a thermodynamic system. Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy and heat between physical systems.

1. Modes of heat transfer

The fundamental modes of heat transfer are:

1) Conduction or diffusion
2) Convection
3) Radiation

1. Conduction

Conduction is the transfer of heat energy by microscopic diffusion and collisions of particles within a body due to a temperature gradient. The microscopically diffusing and colliding objects include molecules, electrons, atoms, and phonons. Conduction takes place in solids, liquids and gases.

Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is greater in solids because the network of relatively close fixed spatial relationships between atoms helps to transfer energy between them by vibration. Fluids are less conductive. This is due to the large distance between atoms in a gas. Conductivity of gases increases with temperature.

Steady-state conduction : Steady state conduction is the form of conduction that happens when the temperature difference is constant. In steady state conduction, the amount of heat entering any region of an object is equal to amount of heat coming out . There is no change in the internal energy of the system during such process. Typical examples of steady state heat transfer are :

- Cooling of an electric bulb by the surrounding atmosphere
- Heat flow from the hot to cold fluid in a heat exchanger

Unsteady state conduction : When the temperatures are changing in an object with respect to time, the mode of heat transfer is termed as unsteady state conduction. A change in temperature indicates a change in internal energy of the system. Energy storage is thus a part of unsteady heat flow. Typical examples of unsteady heat transfer are :

- Warm-up periods of furnaces
- Boilers and turbines
- Cooling of castings in a foundry.

Transient conduction : It is a special kind of unsteady process in which the system is subjected to cyclic variations in the temperatue of its environment. The temperature at a particular point of the system returns periodically to the same value. The rate of heat flow and energy storage also undergo periodic variations. Typical example include :

- Heating and cooling of the water of an I.C engine.

2. Convection

Convection is the transfer of thermal energy from one place to another by the movement of fluids or gases. Convection is usually the dominant form of heat transfer in liquids and gases. Convection describes the combined effects of conduction and fluid flow or mass exchange. Two types of convections are described below:

Natural of free convection : It is a type of heat transfer, in which the fluid motion is not generated by any external source but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming a convection current. This process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density. Because of this, the presence of a proper acceleration such as arises from resistance to gravity, or an equivalent force, is essential for natural convection. Examples of natural convection include:

- The upward flow of air due to a fire or hot object
- The circulation of water in a pot that is heated from below.
- Cooling of billets in the atmosphers

Forced convection : It is a type of transfer in which fluid motion is generated by an external source,like a pump, fan, suction device, etc. It should be considered as one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently. Forced convection is often encountered by engineers designing or analyzing heat exchangers, pipe flow, and flow over a plate at a different temperature than the stream. Examples of forced convection include:

- Flow of water in condenser tubes
- Fluid passing through the tubes of a heat exchanger
- Cooling of internal combustion engines

3. Radiation

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation. The mechanism is that bodies with a temperature above absolute zero have atoms or molecules with kinetic energies which are changing, and these changes result in charge- acceleration and/or dipole oscillation of the charges that compose the atoms. This motion of charges produces electromagnetic radiation in the usual way. The main properties of thermal radiation include:

- Thermal radiation emitted by a body at any temperature consists of a wide range of frequencies.
- The dominant frequency (or colour) range of the emitted radiation shifts to higher frequencies as the temperature of the emitter increases. For example, a red hot object radiates mainly in the long wavelengths .
- The total amount of radiation of all frequencies increases steeply as the temperature rises; it grows as t^4, where t is the absolute temperature of the body.
- The rate of electromagnetic radiation emitted at a given frequency is proportional to the amount of absorption from the source. Thus, a surface that absorbs more red light thermally radiates more red light.

Examples of thermal radiation include:

- The visible light from sun
- TheInfrared light emitted by an incandescent light bulb
- The Infrared radiation emitted by animals

3. Heat transfer by conduction

1. Fourier's Law

The *law of heat conduction*, also known as ***Fourier's law***, states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area, at right angles to that gradient, through which the heat is flowing. Mathematically,

$$Q \propto A \frac{dt}{dx} \quad \text{or} \quad Q = -k A \frac{dt}{dx}$$

where, Q = Amount of heat flow in a unit time (kJ/s)

A = Surface area of heat flow, taken at right angles to the direction of flow (m^2)

dt = Temperature difference on the two faces of the body (K)

dx = Thickness of the body through which heat flows, taken along the direction of flow (m)

k = Constant of proportionality known as thermal conductivity of the body (W/mK)

4. Heat transfer by convection

1. Newton's law of cooling

The convective heat transfer between a surface and an adjacent fluid is prescribed by Newton's law of cooling. It states that the rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings.

Mathematically, $Q \propto (t_s - t_f)$ or $Q = h\ A\ (t_s - t_f)$

where

Q =Convective heat flow rate (Joules)

A =Area exposed to heat transfer (m^2)

h =Convective heat transfer co-efficient ($W/\ m^2\ K$)

t_S =Surface temperature (K)

t_f =Fluid temperature (K)

2. Heat exchanger

Heat exchanger is a process equipment designed for the effective transder of heat energy between two fluids.The purpose may be either to remove heat from a fluid or to add heat to a fluid.

Examples include:

- Boilers, superheaters and condensers of a power plant
- Automobile radiators and oil coolers of heat engines
- Condensers and evaporators in refrigeration units
- Water heaters and coolers

Based on the direction of flow of fluids, the heat exchangers are classified into three types:

- Parallel flow heat exchangers
- Counter flow heat exchangers
- Cross flow heat exchangers

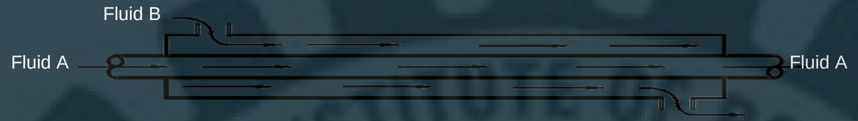


Fig.4.4 Parallel flow heat exchanger

Parallel flow heat exchangers : In parallel flow arrangement, the fluid (hot and cold) enter the unit from the same side, flow in the same direction and subsequently leave from the same side. Obviously the flow of fluids is unidirectional and parallel to each other.

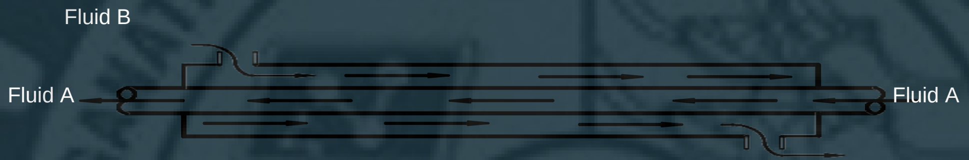


Fig.4.5 Counter flow heat exchanger

Counter flow heat exchangers : In counter flow arrangement, the fluid (hot and cold) enter the unit from opposite ends, travel in opposite directions and subsequently leave from opposite ends. Obviously the flow of fluid is opposite in direction to each other. For a given surface area, the counter-flow arrangement gives the maximum heat transfer rate and is naturally preferred for the heating and cooling of fluids.

Fig.4.6 Cross flow heat exchanger

Cross flow heat exchangers : In the cross-flow arrangement, the two fluids (hot and cold) are directed at right angles to each other. Figure shows the common cross flow arrangements. When mixing occurs, the temperature variations are primarily in the flow direction. When unmixed, ther is temperature gradient along the stream as well as in the direction perpendicular to it. Apparently, temperaturess of the fluids leaving the unit are not uniform for the unmixed streams. The cross flow heat exchangers are commonly employed in air or gas heating and cooling applications.

3. Overall heat transfer cofficient

A heat exchanger is ennentially a device in which energy is transferred from one fluid to another across a good conducting solid wall. Therefore the heat transfer is the combined effect of conduction and covection. In this case an overall heat transfer coefficient is used. Mathematically,

$$U = \frac{1}{\frac{1}{h_i} + \frac{\delta}{k} + \frac{1}{h_0}}$$

where

Q =Overall heat transfer coefficient

h_i =Convective heat transfer coefficient of inner surface

h_0 =Convective heat transfer coefficient of outer surface

k =Thermal conductivity of heat exchanger material

δ =Thickness of the material

3. Logrithmic mean temperature difference (LMTD)

During heat exchange between two fluids, the temperature of the fluids change in the direction of flow. In a parallel flow system, the thermal head causing the flow of heat is maximum at the inlet. However, the thermal head goes on decreasing along the flow path and is minimum at the outlet. In a counter flow system, both the fluids are in their coldest state at the exit. To calculate the rate of heat transfer, an average value of the temperature difference between the fluids has to be determined. It is known as logrithmic mean temperature difference (LMTD).

Unit – II Chapter 3. STEADY FLOW ENERGY EQUATION AND APPLICATIONS

1. Introduction

In a steady flow system, the rates of flow of mass and energy across the control surface are constant. In other words, at the steady state of a system, any thermodynamic property will have a fixed value at particular location, and will not change with time.

Example: The flow system in boiler, steam condenser, steam nozzles and air compressors are examples of steady flow system.

1. Steady flow energy equation (SFEE)

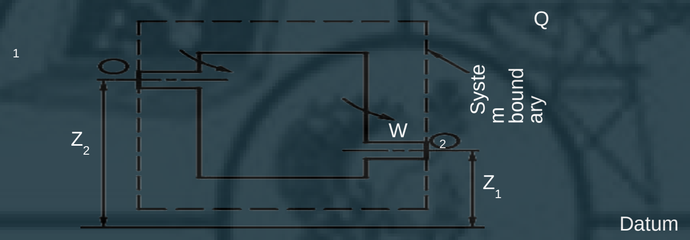


Fig.5.1 Steady flow system

Consider a thermodynamic system as shown in the figure, in which the rate of fluid flow is constant. Fluid enters the system at point 1 and leaves the system at point 2.

Assumptions made in the system analysis

1. The rate of flow of mass and energy through the control volume is constant.
2. Only potential, kinetic, internal and flow energies are considered. Other forms of energies are neglected.
3. The rate of work and heat transfer between the system and surroundings is constant.
4. The properties of fluid at any point remain constant at all times.

Let, p_1 = Intensity of pressure at the inlet

u_1 = Internal energy at inlet

C_1 = Velocity of flow at the inlet

Z_1 = Height above the datum at the inlet

v_1 = Specific volume of the fluid at the inlet

h_1 = Enthalpy of working fluid at the inlet

p_2, u_2, C_2, v_2, and h_2 are the corresponding values at the outlet

Q = Heat transfer during the flow through system

W = Work transfer during the flow through the system

Total energy entering the system

= Potential energy + Kinetic energy + Internal energy + Flow energy + Heat transfer

$$= g.Z_1 + \frac{C_1^2}{2} + u_1 + p_1.v_1 + Q$$

Total energy leaving the system

= Potential energy + Kinetic energy + Internal energy + Flow energy + Work transfer

$$= g.Z_2 + \frac{C_2^2}{2} + u_2 + p_2.v_2 + W$$

By law of conservation of energy,

Energy entering the system = Energy leaving the system

$$g.Z_1 + \frac{C_1^2}{2} + u_1 + p_1.v_1 + Q = g.Z_2 + \frac{C_2^2}{2} + u_2 + p_2.v_2 + W$$

The above equation is called steady flow energy equation.

We know that, $u + p.v = h$

∴ The above equation can be written as,

$$g.Z_1 + \frac{C_1^2}{2} + h_1 + Q = g.Z_2 + \frac{C_2^2}{2} + h_2 + W$$

If 'm' is the mass flow rate of the fluid, the steady flow energy equation may be written as,

$$m\left[g.Z_1 + \frac{C_1^2}{2} + h_1\right] + Q = m\left[g.Z_2 + \frac{C_2^2}{2} + h_2\right] + W$$

3. **Application of steady flow energy equation**

The application of steady flow energy equation includes the following:

a) Steam generators (Boilers) b) Steam condensers
c) Steam nozzles d) Air compressors
e) Steam or gas turbines f) Air heaters, etc.

a) Steam generator or boiler

The main function of the boiler is to transfer the heat to the steady flow system (water). The heat transfer takes place at constant pressure.

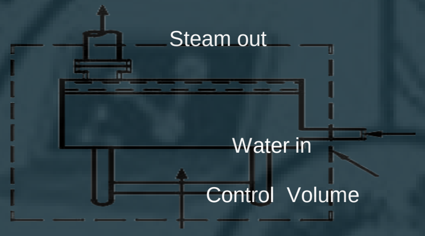


Fig. 5.2 Steam generator

In a boiler,

i) No mechanical work is done. ∴ $W=0$
ii) Fluid velocity at the inlet and exit is small. ∴ There is no change in kinetic energy, i.e. $C_1 = C_2$
iii) Potential energy between inlet and exit is also negligible, i.e. $Z_1 = Z_2$

Applying steady flow energy equation to inlet and exit,

$$h_1 + Q = h_2$$

or, Heat transfer, $Q = h_2 - h_1$ J/kg.

b) Steam condenser

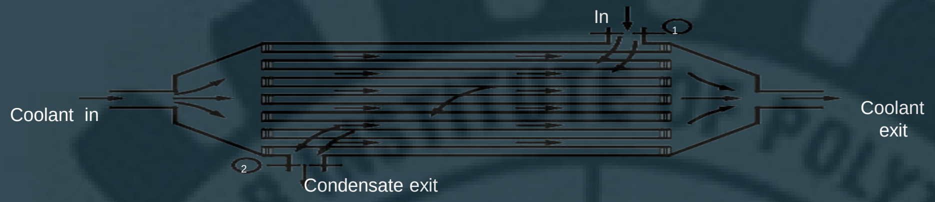


Fig. 5.3 Steam condenser

In a condenser,

i) No work is done **(W=0)**

ii) No change in kinetic energy ($C_1 = C_2$)

iii) No change in potential energy ($Z_1 = Z_2$)

The steady flow energy equation will be reduced to, $h_1 + Q = h_2$

or, heat transfer, $Q = h_2 - h_1$ J/kg.

c) Steam nozzles

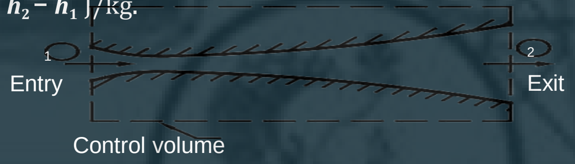


Fig.5.4 Steam nozzle

Nozzle is a device used for increasing the velocity of flowing fluid at the cost of pressure drop. IN a nozzle,

i) No work is done **(W=0)**

ii) No heat transfer takes place **(Q=0)**

iii) No change in potential energy ($Z_1 = Z_2$)

The steady flow energy equation can be written as,

$$\frac{C_1^2}{2} + h_1 = \frac{C_2^2}{2} + h_2 \quad \text{or,} \quad \frac{C_2^2}{2} - \frac{C_1^2}{2} = h_1 - h_2$$

This equation shows that enthalpy of the system is reduced. The energy lost is converted into the kinetic energy.

$$C_2^2 - C_1^2 = 2(h_1 - h_2)$$

or, final velocity, $C_2 = \sqrt{2(h_1 - h_2) + C_1^2}$

e) Steam turbine and gas turbines

A steam turbine is a device which converts the energy of steam into mechanical work. Steam is expanded through a nozzle and a certain amount of heat energy is converted into kinetic energy. The steam with high velocity flows over curved blades and its direction of motion is changed. This causes a change of momentum and force thus developed drive the turbine shaft.

In a gas turbine, air is compressed in a compressor. This air is heated by the combustion of fuel. The hot products of combustion is expanded in turbine blades, thus doing mechanical work.

In both the turbines, expansion of working fluid is treated as reversible adiabatic (isentropic). Neglecting the changes in the potential and kinetic energies, steady flow energy equation is written as,

$$h_1 = h_2 + W$$

or, Work input, $\boldsymbol{W = h_1 - h_2}$

5.4 Non flow energy equation

In a closed system, there is no mass transfer across the boundary. Hence the flow energy, kinetic energy and potential energies are neglected. Therefore for a closed system, the energy equation is written as,

$$u_1 + Q = u_2 + W$$

or, $Q = W + u_2 - u_1$

$$\boldsymbol{Q = W + \Delta u}$$

Unit – III
INTERNAL COMBUSTION ENGINES

1. Introduction

A machine which converts heat energy into mechanical work is known as heat engine. Internal combustion (I.C) engine is a heat engine in which combustion of fuel takes place inside the engine cylinder.

Example: Petrol engine, diesel engine, gas engine, gas turbine, etc.

If the combustion takes place outside the working cylinder, then it is called external combustion engine.

Example: Steam engines and steam turbines.

1. Classification of I.C. engines

Internal combustion engines may be classified according to

1. The type of fuel used

a) Petrol engines b) Diesel engines c) Gas engines

2. Number or strokes per cycle

a) Four stroke engine b) Two stroke engine

3. Method of ignition

a) Spark Ignition (S.I) engines

b) Compression Ignition (C.I) engines

4. Cycle of operation

a) Otto cycle engines b) Diesel cycle engines

c) Dual combustion cycle engines

5. Arrangement of cylinders

b) Vertical engines b) Horizontal engines c) V-type engines

d) In-line engines e) Radial engines

6. Cooling system used

b) Air cooled engines b) Water cooled engines

7. Method of fuel injection

a) Carburetor engines b) Air injection engines

c) Airless or solid injection engines

5. Number of cylinders

b) Single cylinder engines b) Multi-cylinder engines

9. Method of governing

b) Quantity governed engine b) Quality governed engines

c) Hit and miss governed engines

10. Location of valves

a) Overhead valve engines b) Side valve engines

11. Method of lubrication

a) Wet sump engines b) Dry sump engines

12. Speed of the engine

a) Low speed engines b) Medium speed engines

c) High speed engine

8.3 Major components of I.C. engines

The figure shows the constructional details of a four stroke cycle petrol engine. The major components of the engine are explained below.

1. Cylinder block

It is the main part of the engine. It contains cylinders. The cylinders are accurately finished to accommodate piston. The cylinder block houses piston, crank, connecting rod, cam shaft and other engine parts. In water cooled engines, the cylinder block is provided with water jackets for the circulation of cooling water. The materials used for making cylinder block are grey cast iron, aluminium alloys, etc.

2. Cylinder head

The cylinder head is bolted to the top of cylinder block by means of studs. The cylinder block contains inlet and exhaust ports and valves. In the cylinder head, a spark plug is provided in the case of petrol engine and a fuel injection nozzle is provided in the case of diesel engine. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint. The materials used for making cylinder head are cast iron, aluminium alloy, etc.

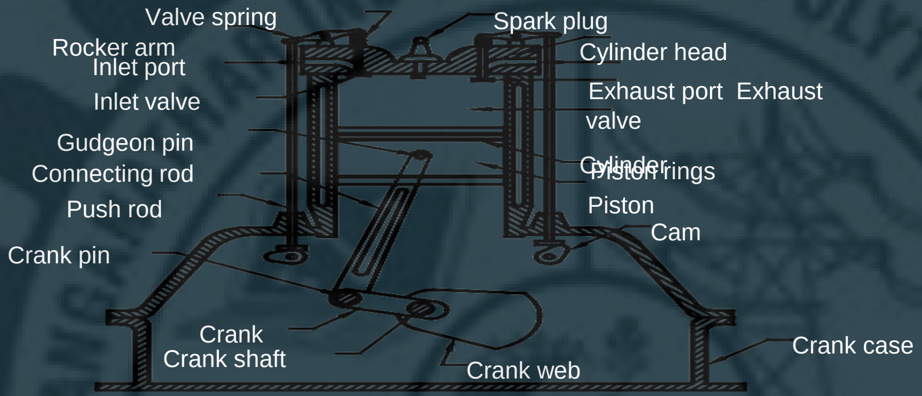


Fig.8.1 Four stroke cycle petrol engine

3. Cylinder liners

The liner is a sleeve, which is fitted into the cylinder bore. It provides wear resisting surface for the cylinder bores. Liners may be of two types : (a) Dry liners and (b) Wet liners.

(a) *Dry liners:* Dry liners have metal–to–contact with the cylinder block. They are not directly in touch with cooling water.

(b) *Wet liners:* These liners are surrounded or wetted by cooling water. It provides wear resisting surface for the piston to reciprocated. Also it acts as a seal for the water jacket.

Liner material should withstand abrasive wear and corrosive wear. Chromium plated mil steel tubes are used as liners. Good quality cast iron liners produced by centrifugal casting is also commonly used in engines.

4. Crank case

It may be cast integral with the cylinder block. Some times, it is cast separately and fitted to the cylinder block. It also serves as a sump for the lubricating oil. The material used for crankcase are cast iron, alumimium alloys or alloy steels.

5. Oil pan or oil sump

Oil sump is the bottom part of the engine. It contains lubricating oil. A drain plug is provided in the oil sump to drain out the oil. It is made of pressed steel sheet.

6. Piston

The piston is a cylindrical part. The main function of the piston is to transmit the force exerted to the burning of fuel in the cylinder to crank shaft through connecting rod. It also acts as a movable gas tight seal to keep the gases inside the cylinder. It is opened the bottom and closed at the top. The top of the piston is called *crown*. The bottom portion is called *skirt*. Three grooves are provided on the circumference of the piston to fit piston rings. The piston may be made of cast iron, aluminium alloy or cast steel.

7. Piston rings

Compression rings and oil rings are inserted in the grooves provided on the piston. Compression rings provide an effective seal for the high pressure gases inside the cylinder. At least two compression rings are provided in each piston.

Oil rings wipe off the excess oil from the cylinder walls. This excess oil is returned to the oil sump through the oil holes. Generally piston rings are made of wear resistant materials such as alloy cast iron, alloy steel, etc.

8.Connecting rod

It connects the piston and crank shaft. It transmits the force exerted due to the burning of fuel during power stroke to the crank shaft. The upper end of the connecting rod is fitted to the piston by means of gudgeon pin. The lower end is called big end and is connected to the crank.

The connecting rods must withstand heavy thrusts. Hence it must have more strength and rigidity. The connecting rod is usually made with drop forged I–sections. The materials used for connecting rod are plain carbon steel, aluminium alloys, nickel alloy steels, etc.

9. Crank shaft

Crank shaft is the main rotating shaft of the engine. The main function of crank shaft is to convert the reciprocating motion of the piston into rotary motion with the help of connecting rod. The crank shaft is held in position by the bearings. This shaft contains one or more eccentric portions called cranks. A crank is connected to the connecting rod by a crank pin. Front end of the crankshaft is provided with the following:

(a) *A gear or sprocket:* It drives the camshaft at half the speed of the crankshaft.

(b) *Vibration damper:* It protects the crankshaft from the torsional vibrations set up during power strokes.

(c) *Pulley :* The pulley is fitted with *V*–belts. It drives engine fan, water pumps, dynamo, etc.

The material of the crankshaft must be strong enough to withstand heavy forces of the piston. They are made from carbon steel, nickel–chromium alloy, heat treated alloy steels, etc.

10. Camshaft

Camshaft contains number of cams. It is used to convert rotary motion into linear or straight line motion. It has number of cams equal to the number of valves in an engine. An additional cam is also provided to drive the fuel pump. A gear is provided in the cam shaft to drive the distributor or oil pump. The opening and closing of the engine valves are controlled by the cams provided on the cam shaft. The camshaft rotates inside the main bearings. It is driven by crankshaft through chain or gear drive. It is rotated at half the speed of the crankshaft.

11. Valves

The inlet valve and the exhaust valve are the main valves in an engine. The fresh charge enters into the cylinder through inlet valve. The exhaust gases are forced out of the engine cylinder through the exhaust valves. The opening and closing of these valves are controlled by the cams provided in the camshaft.

Inlet valve is made of plain nickel, nickel–chrome or chrome–molybdenum. The exhaust valve is subjected to more heat. Hence it should be capable of withstanding high temperatures. Exhaust valves are made of silicon–chrome steel, high speed steel, cobalt–chrome steel, nickel–chrome steel and tungsten steel, etc.

12. Valve actuating mechanism

Valve actuating mechanism is provided in an engine to open and close the valves. The following are the important mechanisms:

(a) Side valve mechanism

(b) Overhead valve mechanism

(c) Overhead inlet and side exhaust valve mechanism

(a) ***Side valve mechanism:*** Side valve mechanism consists of valves, valve spring, valve tappet, valve guide, camshaft and its drive, etc. The cam mounted on the camshaft operates the valve tappet. The valve tappet is pushed up. The valve tappet pushes the valve from its seat against the spring force. Thus the valve is opened. When the cam is not in action, the valve returns back to its seat by the valve spring and spring retainer.

(b) ***Overhead valve mechanism:*** This type of mechanism is commonly used in i.c engines. The valves are located in the cylinder head. This mechanism includes valves, valve springs, valve tappet or valve lifter, push rod, rocker arm, etc. The cam mounted on the camshaft moves the valve lifter. The valve lifter pushes the push rod upwards. Push rod moves the rocker arm. The rocker arm pushes the valve off its seat against the spring force. Thus the valve is opened. When the cam is not in action, the valve returns back to its seat by the valve spring and spring retainers.

(c) Overhead inlet and side exhaust valve mechanism: In this system, the inlet valves are located in the cylinder head. They are operated by the overhead valve mechanism. The exhaust valves are located in the cylinder block. They are operated by the side valve mechanism principle.

8.4 Engine parts, materials and manufacturing methods

Sl. No.	Part name	Materials used	Manufacturing method
1.	Cylinder block	Grey cast iron, aluminium alloys, alloy steel, etc.	Casting
2.	Cylinder head	Grey cast iron, aluminium alloys, alloy steel, etc.	Casting or forging
3.	Cylinder head	Cast iron, chromium plated mild steel tubes	Centrifugal casting
4.	Crankcase	Alloy steels, cast iron	Forging, casting
5.	Piston	Cast iron, aluminium alloy, nickel–chrome alloy, cast steel, etc.	Casting or forging
6.	Piston rings	Alloy cast iron containing silicon and manganese, alloy steels, etc.	Casting
7.	Connecting rod	Plain carbon steel, aluminium alloys, nickel alloy steels, etc.	Drop forging
8.	Crankshaft	Hot billet steel, carbon steel, nickel–chrome, other heat treated alloy steels, etc.	Drop forging or casting
9.	Inlet valves	Plain nickel, nickel–chrome, or chrome molybdenum	Forging
10.	Exhaust valves	Silicon chrome steel, high speed steel, cobalt–chrome steel, nickel–chrome steel, tungsten steel, etc.	Forging

8.5 Four stroke cycle petrol engine or spark ignition engine

A four stroke petrol engine requires four strokes of piston to complete one cycle of operation. In petrol engines, as the air fuel mixture is ignited by a spark plug, it is also known as spark ignition engines.

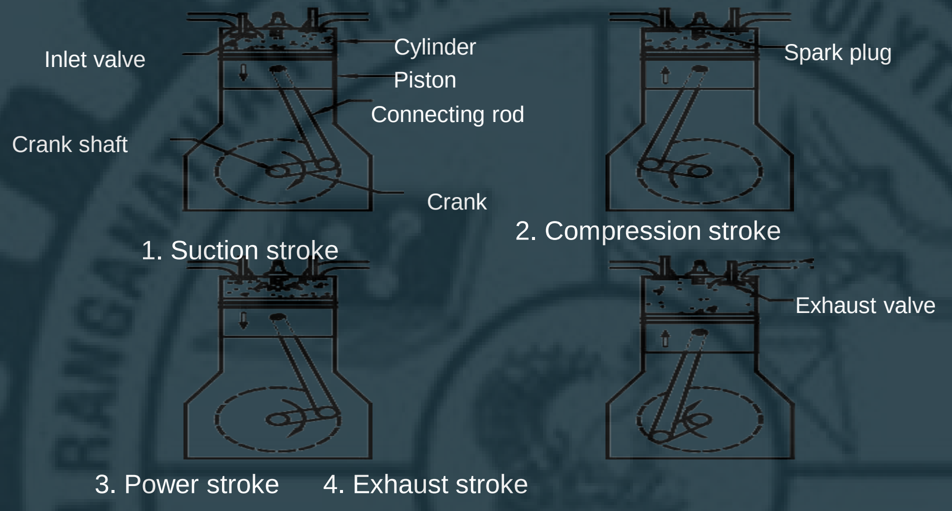


Fig.8.2 Working of four stroke cycle petrol engine

Construction

The engine contains a piston, which reciprocates inside the cylinder. The piston is connected to the crank shaft by means of connecting rod and crank. The inlet and outlet valves are mounted on the cylinder head. A spark plug is also provided on the cylinder head for spark ignition. The events in a four stroke cycle petrol engine are as follows.

1. Suction or charging stroke

In this stroke, the required air–fuel mixture called as charge is sucked into the engine cylinder. During this stroke, piston moves down from Top Dead Centre (TDC) to Bottom Dead Centre (BDC). Due to the downward movement of the piston, the pressure inside the cylinder is reduced below the atmospheric pressure. Now inlet valve opens and fresh air–fuel mixture is sucked into the cylinder through the inlet valve. Exhaust valve remains closed during this stroke.

2. Compression stroke

In this stroke, the air–fuel mixture inside the cylinder is compressed. During this stroke, the piston moves up from BDC to TDC and both the inlet and outlet valves are kept closed. Due to the upward movement of the piston, the air–fuel mixture in the cylinder is compressed. As a result of compression, the pressure and temperature of air–fuel mixture increases considerably. This completes one revolution of crank shaft.

Ignition: When the piston reaches near TDC, an electric spark is produced by the spark plug. The compressed air–fuel mixture is ignited by the spark. It results in a sudden increase of temperature and pressure of combustion products. However, the volume remains constant during combustion.

3. Expansion stroke or working stroke or power stroke

In this stroke, the heat energy is converted into useful mechanical work. The burning gases expand rapidly. A force is exerted on the piston due to the high pressure and expansion of hot gases. Now the piston is pushed downward from TDC to BDC. The movement of the piston is converted into rotary motion of the crank shaft through connecting rod. Thus, the heat energy is transformed into useful mechanical work. Both inlet and exhaust valves are closed during this stroke.

4. Exhaust stroke

In this stroke, the burnt gases are exhausted from the cylinder. Now the exhaust valve is opened. The piston moves upward from BDC to TDC. This movement of piston pushes out the burnt gases to the atmosphere through exhaust valve. During this stroke, the inlet valve remains closed. This completes one cycle and the cylinder is ready to suck air–fuel mixture to start a new cycle.

Thus in a four stroke engine, there is only one power stroke and three idle strokes. The power stroke supplies the required momentum to carry out all other strokes. Thus the engine is kept running

8.6 Two stroke cycle petrol engine

A two stroke engine require two strokes of piston to complete one cycle of operation. It means that the suction, compression, expansion and exhaust are completed in two strokes of the piston. Thus, in a two stroke engine, there is one power stroke for every revolution of crank shaft.

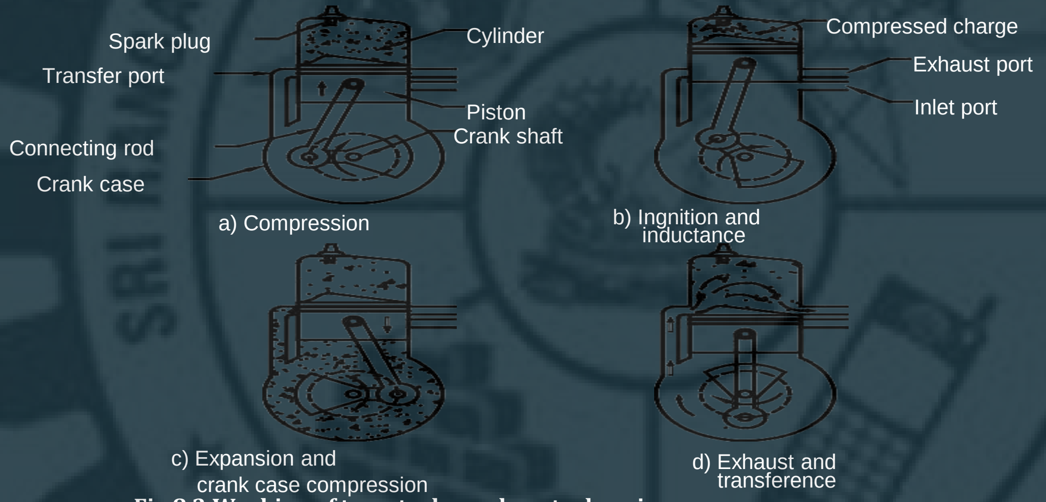


Fig.8.3 Working of two stroke cycle petrol engine

Construction

The engine contains a piston, which reciprocates inside the cylinder. The piston is connected to the crank shaft by means of connecting rod and crank. In two stroke engines, ports are provided in the cylinder walls instead of valves. There are three ports namely inlet port, exhaust port and transfer port. The closing and opening of the ports is obtained by the movement of the piston. The crown of the piston is made with a shape so as to deflect the air–fuel mixture upwards inside the cylinder. A spark plug is also provided on the cylinder head for spark ignition. The events in a two stroke cycle petrol engine are as follows.

1. First stroke (upward movement) of the piston

During the upward movement of the piston, compression, ignition and inductance of air–fuel mixture take place.

a) Compression

The piston moves from BDC to TDC. Both transfer and exhaust ports are covered by the piston. Due to the upward movement of the piston, the air–fuel mixture which is transferred already into the engine cylinder is compressed by the piston. As a result of compression, the pressure and temperature of air–fuel mixture increases considerably.

b) Ignition and inductance

When the piston reaches near TDC, an electric spark is produced by the spark plug. The compressed air fuel mixture is ignited by the spark. It results in a sudden increase of temperature and pressure of combustion products.

At the same time, the inlet port is uncovered by the piston. Now the fresh air–fuel mixture from the carburetor enters into the crank case through the inlet port.

2. Second stroke (downward movement) of the piston

During the downward movement of the piston, expansion of hot gases, crank case compression of air–fuel mixture, exhaust of burnt gases and transference of air–fuel mixture take place.

c) Expansion and crank case compression

The burning gases expand rapidly in the cylinder. A force is exerted on the piston due to the high pressure and expansion of hot gases. Now the piston is moved downward. The movement of the piston is converted into rotary motion of crank shaft through connecting rod. Thus, the heat energy is transformed into useful mechanical work.

When the piston moves downward, the air–fuel mixture inside the crank case is partially compressed. This process is known as *crank case compression.*

d) Exhaust and transference

When the piston further moves downward, the exhaust port is uncovered. The burnt gases escape to atmosphere through exhaust port. The transfer port is also opened. The partially compressed air fuel mixture inside the crank case enters into the cylinder through transfer port. Due to the deflected shape in crown of the piston, the air–fuel mixture is deflected upwards inside the cylinder. Thus, the escape of fresh air–fuel mixture along with exhaust gases is reduced.

Again, when the piston moves up, the transfer port is first closed and then the exhaust port is closed. The air–fuel mixture inside the cylinder is compressed. When the piston reaches near TDC, the inlet port is uncovered. Fresh air–fuel mixture enters into the crank case. At the same time, the compressed air–fuel mixture is ignited and the cycle is repeated.

Application

The two stroke cycle petrol engines are generally used in light vehicles such as scooters, motor cycles, three wheelers, etc.

8.7 Four stroke cycle diesel engine or compression ignition (C.I) engine

A four stroke diesel engine requires four strokes of piston to complete one cycle of operation. In diesel engines, as the air–fuel mixture is ignited due to the temperature developed by the compression, it also known as *compression ignition engines.*

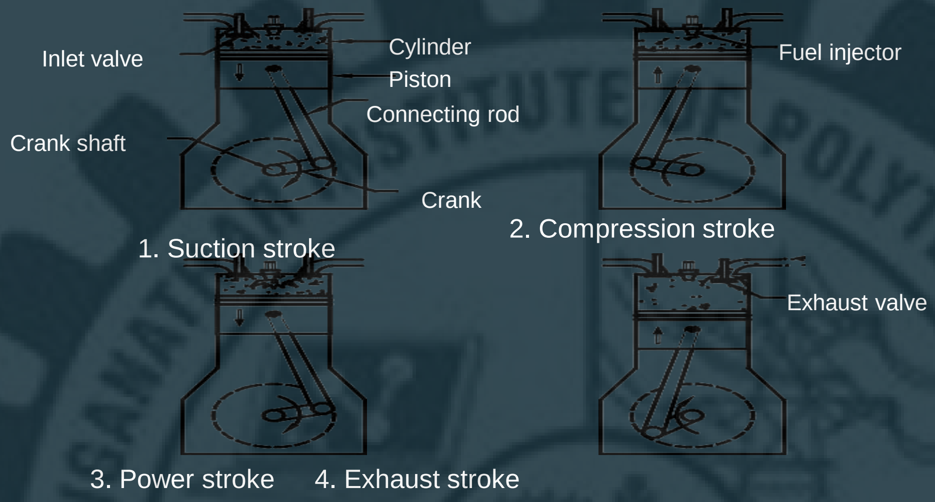


Fig.8.4 Four stroke diesel engine

Construction

This engine contains a piston, which reciprocates inside the cylinder. The piston is connected to the crank shaft by means of connecting rod and crank. The inlet and outlet valves are mounted on the cylinder head. A fuel injector is also provided on the cylinder head for injection of fuel. The events in four stroke cycle diesel engine are as follows.

1.Suction stroke

In this stroke, the air is sucked into the engine cylinder. During this stroke, piston moves down from Top Dead Centre (TDC) to Bottom Dead Centre (BDC). Due to the downward movement of the piston, the pressure inside the cylinder is reduced below the atmospheric pressure. Now the air from the atmosphere is sucked into the cylinder through the inlet valve after filtering. The exhaust valve remains closed during this stroke.

2. Compression stroke

In this stroke, the air inside the cylinder is compressed.
During this stroke, the piston moves up from BDC to TDC and both the inlet and outlet valves are kept closed. Due to the upward movement of the piston, the air in the cylinder is compressed. As a result of compression, the pressure and temperature of air increases considerably. This completes one revolution of crank shaft.

Ignition: When the piston reaches near TDC, the fuel is injected into the cylinder in the form of fine spray with the help of fuel injector. Due to high pressure and temperature of compressed air, the air–fuel mixture is ignited. It results in a sudden increase of temperature and pressure of combustion products. However, the volume remains constant during combustion.

3. Expansion stroke or working stroke or power stroke

In this stroke, the heat energy is converted into useful mechanical work. The burning gases expand rapidly. A force is exerted on the piston due to the high pressure and expansion of hot gases. Now the piston is pushed downward from TDC to BDC. The movement of the piston is converted into rotary motion of the crank shaft through connecting rod. Thus, the heat energy is transformed into useful mechanical work. Both inlet and exhaust valves are closed during this stroke.

4. Exhaust stroke

In this stroke, the burnt gases are exhausted from the cylinder. Now the exhaust valve is opened. The piston moves upward from BDC to TDC. This movement of piston pushes out the burnt gases to the atmosphere through exhaust valve. During this stroke, the inlet valve remains closed. This completes one cycle and the cylinder is ready to suck air to start a new cycle.

Thus in a four stroke engine, there is only one power stroke and three idle strokes. The power stroke supplies the required momentum to carry out all other strokes. Thus the engine is kept running

Application

The diesel engines are relatively slow speed engines and they are generally used in heavy duty vehicles such as buses, trucks, earth moving machines, etc.

8.8 Comparison of two stroke and four stroke engines

	Two stroke engines	Four stroke engines
1.	The power stroke is obtained in one revolution of the crank shaft	One power stroke is obtained in two revolutions of the crank shaft.
2.	Simple in design and lighter in weight	Complicated design and heavier in weight
3.	The torque obtained is uniform	The torque obtained is not uniform
4.	Starting is easy	Starting is not so easy
5.	Mechanical efficiency is high	Mechanical efficiency is low
6.	Air cooling is generally used	Water cooling is generally used
7.	Fuel consumption is more	Fuel consumption is less
8.	Consumption of lubricating oil is more	Consumption of lubricating oil is less
9.	Some of the fuel may escape with exhaust gases	Fuel cannot escape with exhaust gases
10.	Thermal efficiency is less	Thermal efficiency is more
11.	Wear and tear of the moving parts is more	Wear and tear of the parts is less
12.	It gives more noise	Noise is less
13.	The initial cost and maintenance cost are less	The initial cost and maintenance cost are more
14.	These engines are generally used in light vehicles such as motor cycles, scooters, mopeds, etc.	These engines are generally used in heavy vehicles such as buses, lorries, trucks, etc.

8.9 Comparison of petrol (S.I) engine and diesel (C.I) engine

	Petrol (S.I) engines	Diesel (C.I) engines
1.	It works on the basis of Otto cycle	It works on the basis of Diesel cycle
2.	Air–fuel mixture is sucked into the cylinder during suction stroke	Air alone is sucked into the cylinder during suction stroke
3.	Petrol engine operates with low pressure and temperature	Diesel engine operates with high pressure and temperature
4.	Carburetor and spark plugs are provided	Fuel injection pump and injectors are provided
5.	Ignition of air–fuel mixture takes place by an electric spark produced by the spark plug	Ignition of air–fuel mixture takes place due to the heat developed by the compression of air
6.	They are quantity governed engines	They are quality governed engines
7.	Operating speed is more	Operating speed is less
8.	Weight per unit power is less	Weight per unit power is more
9.	Starting is easy	Starting is not so easy
10.	Initial cost and maintenance cost are less	Initial cost and maintenance cost are more
11.	These engines produce less noise	These engines produce more noise
12.	Thermal efficiency is less	Thermal efficiency is more
13.	Fuel consumption per unit power is more	Fuel consumption per unit power is less
14.	The cost of petrol is more	The cost of diesel is less than petrol
15.	Petrol engines are widely used in light vehicles, automobiles, airplanes, etc.	Diesel engines are widely used in heavy vehicles such as buses, lorries, trucks, tractors, etc.

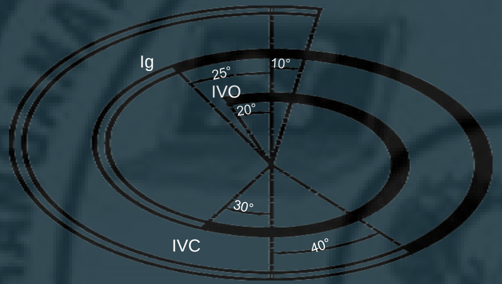
10. Valve timing diagram (V.T.D)

The valves in an i.c engines are assumed to open and close at the dead centre positions of the piston. But, in actual practice the valves operate some degrees before or after the dead centres for the better utilization of charge. The ignition is also timed to occur a little before the top dead centre. The timings of these sequence of events are represented graphically in terms of crank angle from dead centre position. This diagram is known as valve timing diagram.

1. Valve timing diagram for four–stroke petrol engine

TDC

EVC



IVO - Inlet valve opens IVC - Inlet valve closes Ig - Ignition
EVO - Exhaust valve opens EVC - Exhaust valve closes

IVO - IVC : Suction
IVC - Ig : Compression
Ig - EVO : Expansion
EVO - EVC : Exhaust
IVO - EVC : Valve overlap

EVO

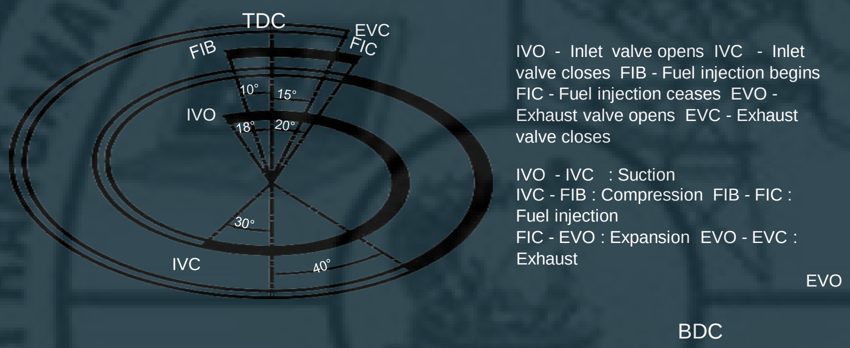
BDC

Fig.8.5 Valve timing diagram for four stroke petrol engine

The valve timing diagram for four stroke petrol engine is shown in the figure 8.5. The inlet valve opens10–30 º before the top dead centre (TDC) position. The air–fuel mixture is sucked into the engine cylinder till the inlet valve closes. The inlet valve closes 30–40 º or even 60 º after the bottom dead centre (BDC) position. The air–fuel mixture is compressed till the spark occurs. The spark is produced 20–40 º before the TDC position. This gives sufficient time for the fuel to burn. The pressure and temperature increases considerably. The burning gases expand and force the piston to do useful work.

The burning gases expand till the exhaust valve opens. The exhaust valve opens 30–60 ° before the BDC position. The exhaust gases are forced out of the cylinder till the exhaust valve closes. The exhaust valve closes 8–20 ° after the TDC position. Before it closes, again the inlet valve opens 10–30 ° before the TDC position. The period between the inlet valve opening and exhaust valve closing is known as valve overlap period. During this period both inlet and exhaust valves are open. The angle between the inlet valve opening and exhaust valve closing is known as angle of valve overlap.

8.10.2 Valve timing diagram for four–stroke diesel engine



IVO - Inlet valve opens IVC - Inlet valve closes FIB - Fuel injection begins FIC - Fuel injection ceases EVO - Exhaust valve opens EVC - Exhaust valve closes

IVO - IVC : Suction
IVC - FIB : Compression FIB - FIC : Fuel injection
FIC - EVO : Expansion EVO - EVC : Exhaust

Fig.8.6 Valve timing diagram for four stroke diesel engine

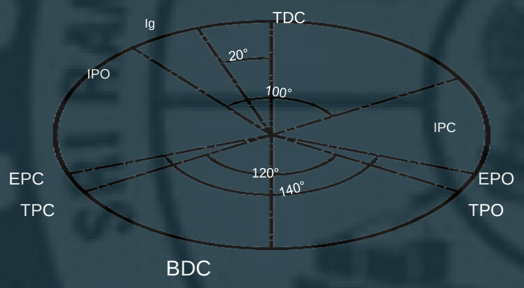
The actual valve timing diagram for four stroke diesel engine is shown in figure 8.6. The inlet valve opens10–25 ° before the top dead centre (TDC) position. Fresh air is sucked into the engine cylinder till the inlet valve closes. The inlet valve closes 25–50 ° after the bottom dead centre (BDC) position. The air is compressed till the fuel is injected. The fuel injection starts 5 ° –10 ° before TDC position in the compression stroke. The air–fuel mixture burns. The pressure and temperature increases considerably. The burning gases expand and force the piston to do useful work.

The burning gases expand till the exhaust valve opens. The exhaust valve opens 30–50 º before the BDC position. The exhaust gases are forced out of the cylinder till the exhaust valve closes. The exhaust valve closes 10–15 º after the TDC position. Before exhaust valve closes, again the inlet valve opens 10–25 º before the TDC position. The period between the inlet valve opening and exhaust valve closing is known as valve overlap period. During this period both inlet and exhaust valves are open. The angle between the inlet valve opening and exhaust valve closing is known as angle of valve overlap.

11. Port timing diagram (P.T.D)

Ports are provided in two–stroke cycle engines. The timings of the sequence of events, such as opening and closing of ports, ignition, etc. are represented graphically in terms of crank angle from dead centre position. This diagram is known as port timing diagram.

1. Port timing diagram of two–stroke petrol engine



IPO - Inlet port opens
IPC - Inlet port closes
TPO - Transfer port opens
TPC - Transfer port closes
Ig - Igniton
EPO - Exhaust port opens
EPC - Exhaust port closes

IPO - IPC : Suction
IPO - TPO : Crank case compression
TPO - TPC : Transfer
TPC - Ig : Compression
Ig - TPO : Expansion
EPO - EPC : Exhaust

Fig.8.7 Port timing diagram for two stroke petrol engine

The port timing diagram of a two–stroke petrol engine is shown in figure 8.7. The inlet port is uncovered (opened) by the piston 45–55 º before TDC position. The inlet port is covered (closed) by the piston 45–55 º after TDC position.

The exhaust port is uncovered by the piston 65–75 ° before the BDC position. The exhaust port is covered 65–75 ° after the BDC position. The transfer port is uncovered and covered by the piston 55–65 ° before and after BDC respectively. Ignition occurs 15–25 ° before the TDC. The sequence of events are given below:

IPO – IPC : Air–fuel mixture is sucked into the crankcase

IPC – TPO : Air–fuel mixture is partially compressed in the crankcase (crankcase compression)

TPO – TPC : Partially compressed air–fuel mixture is transferred into the engine cylinder.

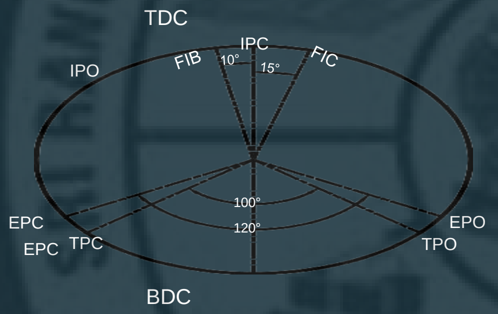
TPC – Ig : Air–fuel mixture is compressed in the cylinder.

Ig : Air–fuel mixture is ignited by an electric spark. Air–fuel mixture burns.

Ig – EPO : The burning gases expand and move the piston to do work.

EPO – EPC : Burnt gases are pushed out of the engine cylinder.

8.11.2 Port timing diagram of two–stroke diesel engine



PVO - Plate valve opens PVC - Plate valve closes TPO - Transfer port opens TPC - Transfer port closes FIB - Fuel injection begins FIC - Fuel injection ceases EPO - Exhaust port opens EPC - Exhaust port closes

PVO - PVC : Air induction
PVC - TPO : Crank case compression
TPO - TPC : Air tranfer
TPC - FIB : Compression
FIB - FIC : Fuel injection FIC - EPO: Expansion
EPO - EPC : Exhaust

Fig.8.8 Port timing diagram for two stroke diesel engine

The port timing diagram of a two–stroke diesel engine is shown in figure 8.8. The plate valve opens after the bottom dead centre position. It remains open till the piston reaches top dead centre. The fuel is injected into the cylinder 10–15 ° before TDC position. Fuel injection continues 15–20 ° after TDC position.

The exhaust port is uncovered and covered by the piston 35–40 º before and after the BDC position respectively. The transfer port is uncovered and covered by the piston 30–35 º before and after BDC respectively. The sequence of events are given below:

PVO – PVC : Air is induced into the crankcase through plate valve

PVC – TPO : Air is partially compressed in the crankcase (crankcase compression)

TPO – TPC : Partially compressed air is transferred into the engine cylinder through transfer port.

TPC – FIB : Air is compressed in the cylinder. The pressure and temperature of the air increases.

FIB – FIC : Fuel is injected into the hot compressed air. Fuel mixes with hot air and burns.

FIC – EPO : The burning gases expand and move the piston to do work.

EPO – EPC : Burnt gases are pushed out of the engine cylinder.

8.12 Fuel supply system in petrol (S.I)engines

The fuel supply system is used to supply required amount of fuel to the engine. Generally, the following fuel supply systems are used in petrol engines.

a) Gravity feed system

b) Pressure feed system or pump feed system

Gravity feed system: In this system, the fuel storage tank is kept at a higher level than the carburetor and the engine. The fuel from the tank flows into the carburetor under gravitation force. This system is employed in motor cycles, scooters, etc.

Fig.8.9 Fuel supply system in petrol engine

Pump feed system: In this system, a feed pump is used to feed the fuel to the carburetor. It consists of a storage tank, fuel pump, fuel filter and carburetor. The fuel tank is mounted away form the engine to avoid fire risk. The fuel pump supplies fuel to the carburetor through a fuel filter. The filter removes dirt, grit and other foreign particles from the fuel. The carburetor supplies required air–fuel mixture to the engine. This system is widely employed in automobiles and air–crafts.

8.13 AC mechanical fuel pump

Fuel pump is used to supply fuel to the carburetor by pumping. A commonly used diaphragm type AC mechanical fuel pump is shown in the figure.

Construction

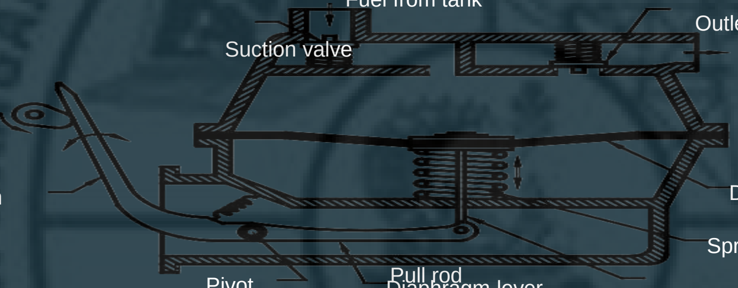


Fig.8.10 AC mechanical fuel pump

This pump consists of a cam, rocker arm, pull rod, lever, diaphragm, inlet and outlet check valves, return springs, etc. The diaphragm is made of high grade cotton impregnated with synthetic rubber. The valves are non–return check valves and made of bakelite. A spring is provided under diaphragm to maintain tension on diaphragm. The bottom of the diaphragm is fitted with a pull rod. One end of the rocker arm is connected to the pull rod and another end slides over the cam, the rocker arm

is pivoted at a point in the pump body.

Working principle

When the cam rotates and pushes the rocker arm, the rocker arm moves towards the body of the pump. This causes the pull rod to pull down the diaphragm through the lever. The pressure inside the chamber falls below the atmospheric pressure. As the result of this pressure difference, the fuel is sucked into the main chamber through the suction valve from the fuel tank. During this movement, the outlet valve remains closed.

When the cam is released from the rocker arm, the rocker arm moves towards the cam shaft. This causes the diaphragm to move upwards by the spring force. The pressure in the main chamber is increased. Now the outlet valve opens and the fuel is pumped out of the main chamber to the carburetor. During this movement, the inlet valve remains closed. The suction and pumping action is repeated continuously and the fuel is pumped to the carburetor from the tank.

8.14 Carburetor

The process of atomizing and vaporizing the fuel and mixing it with air is called *carburetion*. The device used for carburetion is known as *carburetor*.

Functions of a carburetor.

1) It atomizes and vaporizes the fuel.
2) It prepares a mixture of petrol and air in correct proportion.
3) It measures and supplies the proper quantity of air–fuel mixture under all conditions of engine operations.
4) It maintains a small reserve of fuel at a constant head.
5) It provides easy starting of the engine in cold condition.

8.15 Simple carburetor Construction

A simple carburetor is shown in the figure. It consists of a float chamber and a mixing chamber. In the float chamber, a float and a needle valve is provided to maintain a constant level of petrol. The float chamber is vented to atmosphere.

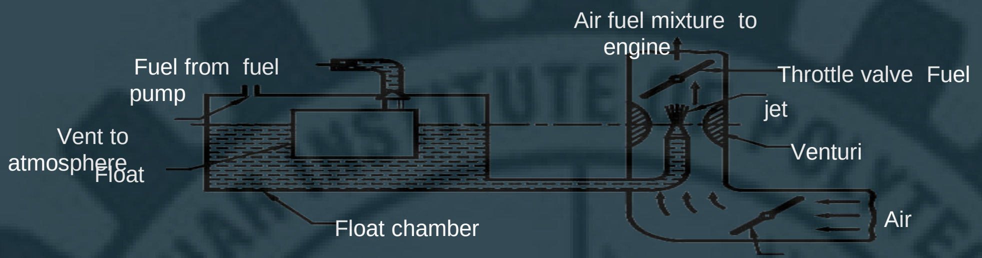


Fig.8.11 Simple carburetor

The mixing chamber contains a constricted section called *venturi*. The fuel is supplied to the jet from the float chamber. The jet keeps same level of petrol as the level in the float chamber. The mixing chamber has two butterfly type valve. One is called *choke valve* and is used to allow air into the mixing chamber. Another one is called *throttle valve* and is used to allow air–fuel mixture to the engine. The outlet of carburetor is fitted to the inlet manifold of the engine to connect inlet valve.

Working principle

When the fuel level goes down in the float chamber, the float also goes down. This opens the needle valve and the fuel enters into the float chamber. When the correct level is reached, the float closes the needle valve. Now fuel supply is stopped.

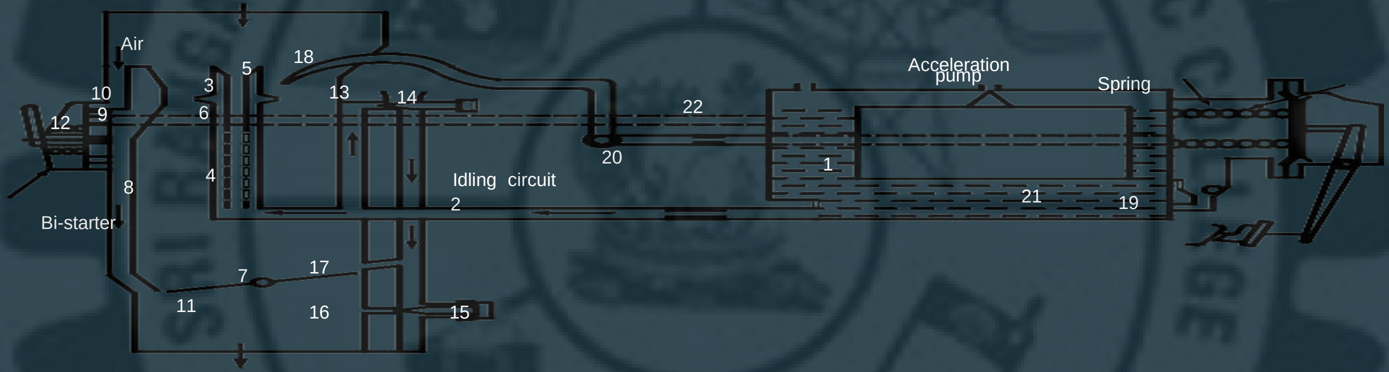
During suction stroke, vacuum is created inside the engine cylinder. This causes pressure difference between the cylinder and outside the carburetor. Due to this pressure difference, atmospheric air flows into the carburetor. When the air passes through the venturi, the velocity of air increases and pressure reduces. Due to this pressure drop, the air sucks the fuel from the jet. The fuel comes out in the form of fine particles and mixes with air to form air–fuel mixture. This air–fuel mixture is supplied to the engine through a throttle valve. The throttle valve is operated by an accelerator to control the amount of air–fuel mixture supplied to the engine.

During cold stating, the choke valve is closed completely. This causes a greater pressure difference and more fuel is sucked from the jet. The engine can be started easily by this rich mixture.

Disadvantages of simple carburetor

1. It is suitable only for engines running at constant speed and load.
2. The working of a simple carburetor is affected by the charges in atmospheric pressure and temperature. It gives rich mixture at high altitude.
3. A week mixture supplied by the carburetor at low speeds may not ignite properly.
4. It gives a weak mixture when the throttle valve is opened suddenly.
5. It does not have arrangement for providing rich mixture during starting and warm up.

8.16 Solex carburettor



1–Float, 2–Main jet, 3–Venturi, 4–Emulsion tube, 5–Air correction jet, 6–Spraying nozzle, 7– Butterfly valve (Throttle valve), 8–Flat disc, 9–starter petrol jet, 10–Starter air jet, 11–Cold starting passage, 12–Bi-starter lever, 13–Pilot jet, 14–Air bleed orifice, 15–Volume control (idle) screw, 16–Idle port, 17–Slow speed opening, 18– Pump injector, 19–Pump lever, 20–Pump jet, 21–Pump inlet valve, 22–Well

Fig.8.12 Solex carburettor

Solex carburettor is mostly used in modern automobiles. Fig.8.12 shows the schematic arrangement of solex carburettor. The drawbacks in simple carburettor can be overcome by using this solex carburettor. The special feature of this carburetor is the provision of bi–starter for cold starting. The working of the solex carburettor is explained below.

Normal running circuit :

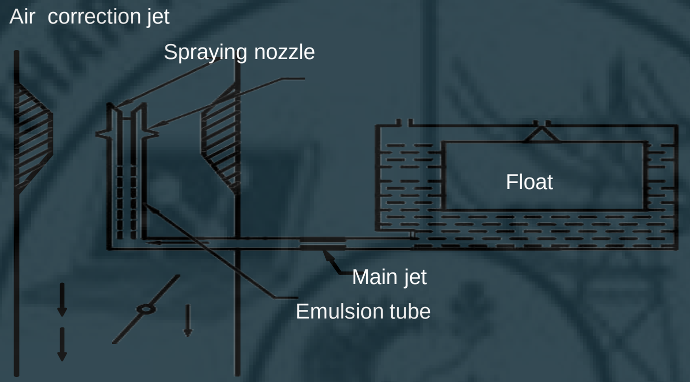


Fig.8.13 Normal running circuit of solex carburettor

The normal running circuit is shown in fig.8.13. During normal running, the air is supplied through the choke tube into the venturi. Petrol is supplied through the main jet. Lateral holes are provided in the emulsion tube. The air passing through this tube draws petrol through the lateral holes. The air–correction jet mixes air and fuel in required ratio. The correct quantity of air–fuel mixture is sprayed through spray nozzles. This mixture is supplied to the engine through the throttle valve.

Cold starting and warming circuit :

The cold starting circuit is shown in fig.8.14. A bi–starter or progressive starter is provided for cold starting. The bi–starter has a flat disc with different size holes. These holes connect the starter petrol jet and starter air jet to the passage. This passage opens just below the throttle valve. The bi–starter lever is operated from the dashboard. This connects either bigger or smaller hole to the passage. For starting, bigger holes are connected to the passage. The throttle valve is closed. The engine suction is applied to the starting passage. More is drawn through the starter petrol jet and less air is drawn through air–jet. Thus a rich mixture is supplied to the engine through the starting passage.

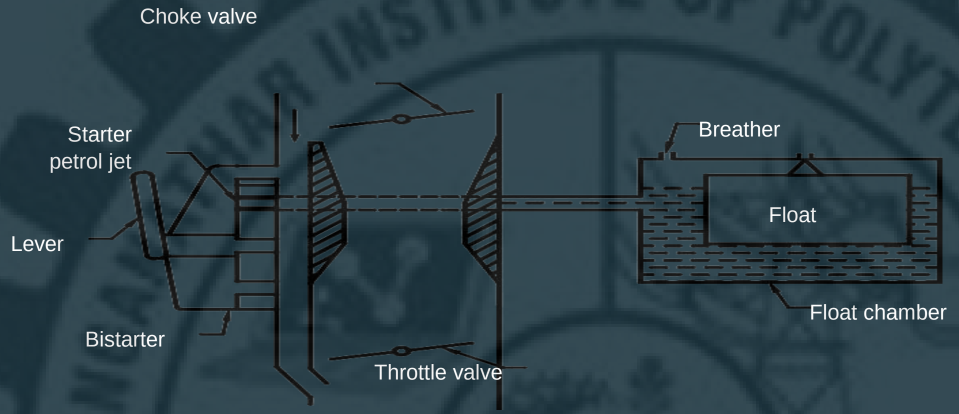


Fig.8.14 Cold starting circuit of solex carburettor

The starter lever is brought to an intermediate position after the engine has started. This connects the smaller hole in the circuit and the fuel supply becomes normal. The starter lever is brought to off position when the engine reaches normal running condition.

Idling and slow running circuit :

The idling and slow running circuit of solex carburettor is shown in fig.8.15. During idling, the engine is kept running while the throttle valve is almost closed. The engine suction is applied at the idle port. Fuel is drawn from the pilot jet. Air is drawn through the small air bleed orifice. The air and fuel mixes together in the idling passage. This air–fuel mixture is supplied to the engine through the idle port. A by pass orifice is provided above the throttle valve. It ensures smooth transfer from the idle circuit to the main circuit and avoids flat spot.

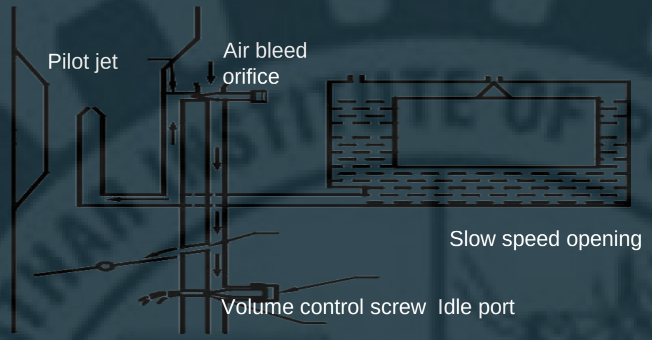


Fig. 8.15 Idling and slow running circuit of solex carburettor

During slow running, the throttle valve is partly opened. The suction at the idle port is not sufficient. The slow speed opening supplies air–fuel mixture to the engine.

Accelerating circuit:

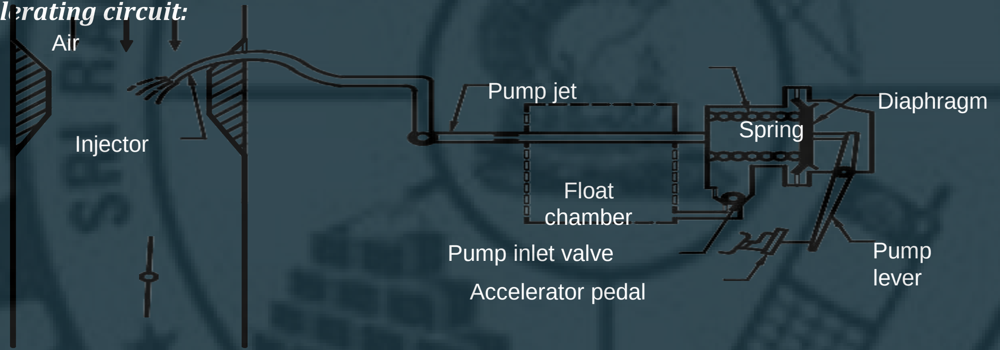


Fig.8.16 Accelerating circuit

Extra fuel is need during acceleration. The acceleration pump injects extra fuel through the pump jet and the pump injector. This pump is actuated by the accelerator through a lever. When accelerator is released, fuel is drawn into the pump through a non–return valve. when the accelerator is pressed down, the lever operates the pump diaphragm. The pump diaphragm moves against the spring and pushes the fuel through pump jet and the pump injector into the venturi.

8.17 Fuel supply system in diesel (C.I) engines

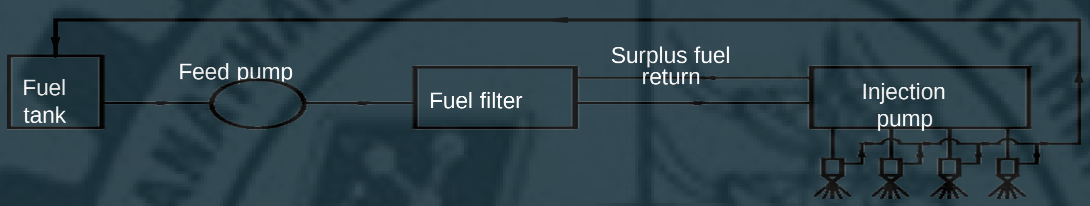


Fig.8.17 Fuel supply system in diesel engine

In diesel engines, the pressure of compressed air reaches 3500 to 4000 KN/m^2 or even above at the end of compression stroke. So the fuel must be injected with a high injection pressure.

The fuel injection system in a diesel engine is shown in the figure. It consists of a fuel tank, fuel feed pump, fuel filter, fuel injection pump and injectors. The fuel from the tank is pumped to the fuel injection pump through the filters by fuel feed pump. From the fuel injection pump, the fuel is delivered to the injector. The injectors spray the fuel into the cylinder as fine particles.

8.18 Fuel injection pump

The main function of fuel injection pump is to deliver correct quantity of fuel to the injector at high pressure. The most widely used CAV fuel injection pump is shown in the figure.

Construction

It consists of a plunger, which reciprocates inside a barrel. The plunger can be rotated by the rack and pinion arrangement. At the same time, the plunger can be moved up and down in the barrel by means of a cam. The plunger has a vertical rectangular groove. This groove extends from the top to another helical groove.

The fuel delivery non–return valve is seated in its seat by spring force. Supply port and spill ports are provided in the barrel. These ports are opened and closed by movement of the plunger. The fuel passage is connected to the fuel injector.

Working principle

When the plunger is at the bottom of its stroke, it uncovers supply port and spill port. Diesel from feed pump is forced into the barrel after filtration. When the cam pushes the plunger, the inlet port and spill port are closed. The fuel above the plunger is compressed. Due to the high pressure, the delivery valve opens against the spring pressure. The fuel flows through the fuel passage to the injectors.

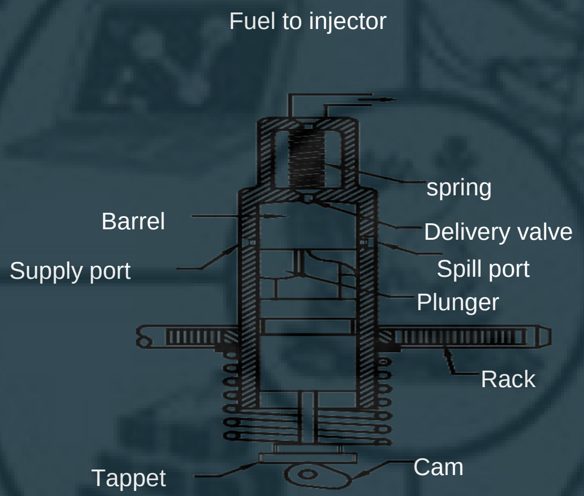


Fig.8.18 CAV fuel injection pump

When the plunger moves up further, the helical groove connect the spill port to the top of the plunger. The remaining fuel escapes through the spill port and the pressure is reduced suddenly. This causes the delivery valve to come back to its seat by the spring force. This cycle is repeated and the fuel is supplied to the injector intermittently.

The quantity of fuel delivered is controlled by the rotary movement of the plunger. The plunger is rotated inside the barrel by using the rack and pinion arrangement. This alters the effective stroke of the plunger and the amount of fuel supply is varied.

8.19 Fuel injector (Atomizer)

The function of a fuel injector is to spray the fuel into the engine cylinder in the form of fine particles at the end of compression stroke.

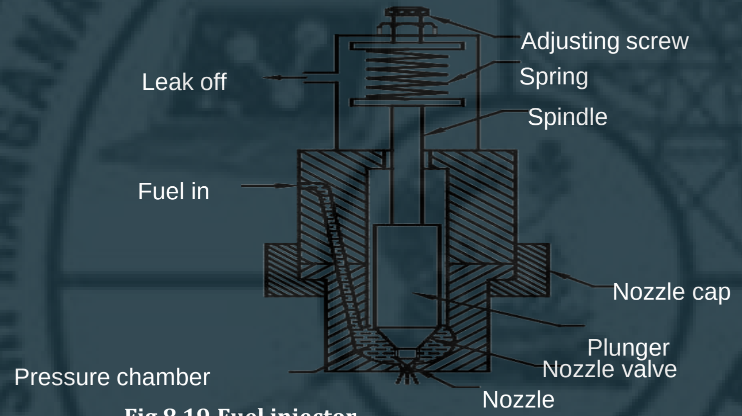


Fig.8.19 Fuel injector

Construction

The fuel injector consists of a nozzle. The nozzle is made with the injector body. The nozzle valve is seated in its seat by spring force. A piston is provided in between the spring and the valve. The tension in the spring can be adjusted by an adjusting screw. A fuel passage is provided in the body of the injector to allow the fuel from the injection pump into pressure chamber. The fuel leaking from the injector is collected and sent back to the tank through leak off passage. The main types of nozzles used in diesel engine are single hole nozzle, multiple hole nozzle and pintle nozzle.

Working principle

The high pressure fuel from the fuel injection pump enters into the injector through the fuel passage. Due to the high pressure of the fuel, the nozzle valve is lifted off its seat against the spring force. Now the fuel is injected into the engine cylinder through the nozzle in the form of fine particles. When the fuel pressure falls, the nozzle valve is brought back to its seat by the spring force. This causes the nozzle hole to close. This process is repeated and the fuel is sprayed into the cylinder at the end of every compression stroke.

8.20 Injection nozzles

The function of the fuel injection nozzle is to inject the fuel delivered by the pump into the combustion chamber. It also atomizes the fuel. The following are the important types of nozzles used in diesel engines.

a) Single hole nozzles (flat and conical end)
b) Multiple hole nozzles (short and long stem)
c) Pintle nozzles
d) Delay type nozzles

a) ***Single hole nozzles:*** This type of nozzle contains a single hole at the end of the nozzle. The fuel passes through this hole into the combustion chamber. It is closed at the inner end by the nozzle valve. Single hole nozzles are available with flat end or conical end. In flat end nozzles, the hole is drilled at he centre of the nozzle axis. In conical type, the hole is drilled at an angle (4^{o} to 15^{o}) to the nozzle axis. Single hole nozzles are used in engines having turbulent chambers.

b) ***Multiple hole (orifice) nozzle :*** This nozzle contains many drilled holes. The number of holes may vary from 3 to 18. It gives finely atomized spray of fuel with greater penetration. They are used in open combustion chambers. They are of two types : (i) Nozzle with axial hole (ii) Long stem nozzles without axial hole.

c) ***Pintle nozzles :*** The pintle nozzle consists of a plunger (pintle) in the fuel passage. This plunger protrudes through the mouth of the nozzle. The movement of the plunger controls the fuel flow into the combustion chamber. The shape of the spindle is made according to the required spray pattern. A hollow cylindrical jet or a hollow cone shaped spray can be obtained by suitably shaping the pintle.

d) ***Delay type nozzles :*** This is also a type of pintle nozzle. The shape of shape of the pintle is change. The shape is in such a way that it reduces the rate of fuel injection at the beginning of the delivery and increases towards the end of delivery. It is used in pre−combustion chambers to reduce the combustion noise when the engine is idling.

21. Fuel filters

The petrol or diesel used in i.c engines may contain impurities such as dust particles, abrasive particles, water droplets, etc. Fuel filters are used to prevent these impurities from going into the fuel pump and engine cylinder.

1. Fuel filter for petrol engines

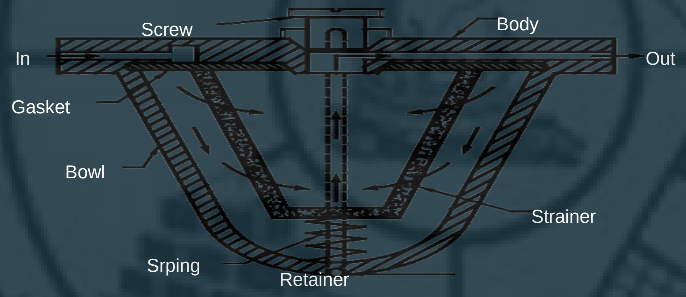


Fig.8.20 Ceramic fuel filter for petrol engine

Different types of fuel filters are used in petrol engines. Nowadays, ceramic type filters are commonly used. If filters out fine particles and water droplets from the fuel before it is supplied to the carburettor. It consists of a glass bowl, ceramic strainer, spring, body, etc. These filters are fitted in between the fuel tank and fuel pump. The fuel is filtered when it passes through the ceramic filter.

The sediments and water are collected at the bottom of the bowl. The filtered fuel enters the fuel pump through the outlet. The sediments settled at the bottom of the bowl may be cleaned periodically by removing the glass bowl.

2. Fuel filter for diesel engines

There are two types of fuel filters are used in diesel engines.

a) Primary filter or pre−filter

b) Secondary filter of micro−filter

a) Primary filter or pre−filter: The primary filter is fitted in between fuel tank and the suction side of the fuel feed pump. The element of this filter is made of nylon mesh or bronze mesh. They filter longer size dust particles above 40 μ m.

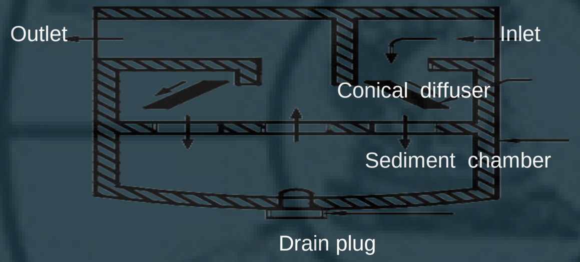


Fig.8.21 Sedimentation type primary filter

The fuel from the tank enters into the filter. It flows around the conical diffuser funnel and moves downward to the sediment chamber. The heavier impurities settle down at the bottom of the sediment chamber. The filtered diesel moves up and passes through the outlet. The impurities collected at the bottom of the chamber can be drained off periodically.

b) Secondary filter or micro−filter : the micro−filter is fitted in between the fuel feed pump and fuel injection pump. The elements of this type of filter are made of cotton, cloth, various of
types of paper or cellulose. They filter out very minute particles (up to 3 μ m) and water content in the fuel.

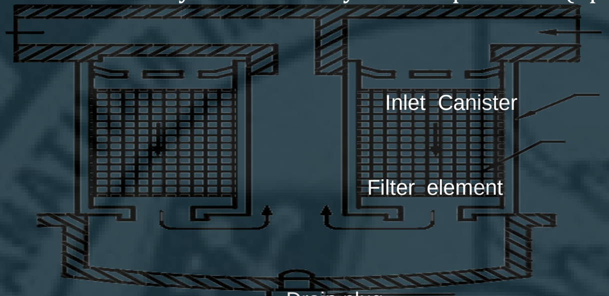


Fig.8.22 Secondary filter or micro filter

The filtering element contains fine pores and it retains the abrasive particles and other solid impurities except water droplets. When water droplets pass through the element, an electrostatic attraction is produced between them by the resin−impregnated element. This causes the droplets to be pulled towards each other and form larger droplets. These heavier droplets settle down in the sediment chamber. The filtered fuel passes through the filter outlet to the fuel injection pump.

8.22 Ignition system of I.C engines

In an internal combustion engine, the air–fuel mixture is ignited at correct instant at the end of compression stroke. This results in efficient and smooth running of the engine. The following two methods are employed in internal combustion engines.

a) Compression ignition (for diesel engines)

b) Spark ignition (for petrol engines)

23. Compression ignition system

This system is used in heavy oil engines working on Diesel cycle. In these engines, fresh air alone is sucked into the engine cylinder during suction stroke. This air is compressed to a high compression ratio ranging from 12 to 20. The pressure and temperature of compressed air at the end of compression are approximately 3500 KN/m^2 and 600^oC respectively. The atomized fuel is injected into the engine cylinder at the end of compression stroke.

The temperature of compressed air is higher than the self ignition temperature of fuel and hence fuel–air mixture is ignited. Since the ignition takes place due to high temperature of compressed air, the diesel engines are known as *compression ignition engines.*

23. Spark ignition system

This system is used in gas engines, petrol engines and light oil engines working on Otto cycle. In this system the air–fuel mixture is ignited by an electric spark produced by the spark plug. The voltage required for producing an electric spark is about 8000 Volts. So, the ignition system in a petrol engine has to step up the battery voltage from 6 volts to 8000 volts. Moreover, it has to provide a spark in each cylinder at the right time. The following ignition methods are used in petrol (S.I) engines.

1) Coil ignition system
2) Magneto ignition system
3) Electronic ignition system

8.24.1 Coil ignition system

Coil ignition system is generally employed in medium and heavy duty petrol engines such as cars. The wiring diagram of a coil ignition system for a four cylinder petrol engine is shown in the figure.

Construction

This system consists of a battery, ignition switch, ignition coil, condenser, contact breaker, distributor and spark plugs. Generally, 6V or 12V battery is used. The ignition coil consists of primary and secondary windings. The primary winding consists of thick wire with few number of turns. The secondary winding consists of thin wire with several thousand turns.

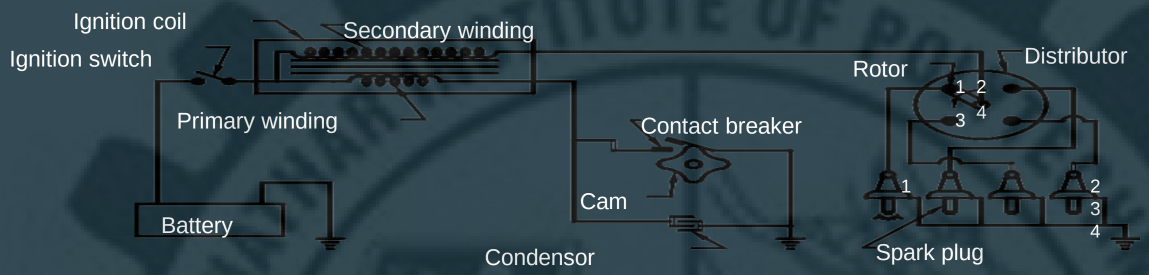


Fig.8.23 Coil ignition system

The circuit of this system can be divided into *primary circuit* and *secondary circuit*. The primary circuit consists of battery, primary winding, condenser and contact breaker. The secondary circuit consists of secondary winding, distributor and spark plugs. One end of the primary coil is connected to the battery through ignition switch. Another end is connected to a condenser and contact breaker.

The contact breaker makes and breaks the primary circuit. The timing of the spark is controlled by the contact breakers. The contact breaker is operated by a cam revolving at half crank speed. The condenser is connected parallel with the contact breaker. If prevents sparking across the gap between the contact breaker points. It also causes a rapid break of the primary circuit, giving higher voltage in the secondary circuit.

The secondary coil is connected to the distributor. A carbon contact carries the current to the revolving rotor arm. The rotor distributes the high voltage to the respective spark plug at regular intervals in the sequence of firing order of the engine. The outer terminal of the spark plugs are earthed together and connected to the body of the engine.

Working principle

The ignition switch is switched on and the engine is cranked. The cranking of the engine opens and closes the contact breaker points through the cam.

When the contact breaker points are closed, the current flows from the battery to the contact breaker through the switch and primary winding. This current sets up a magnetic field around the primary winding of ignition coil. When the primary current is at the highest peak, the contact breaker points are opened by the cam. The magnetic field set up in the primary winding is collapsed suddenly. Due to this, a high voltage (about 10,000 Volts) is generated in the secondary winding of the ignition coil. This high voltage is supplied to the rotor of the distributor. The rotor distributes the high voltage to various spark plugs in the sequence of firing order of the engine. When this high voltage tries to escape through the spark plug gap, an electric spark is produced. This spark ignites the air–fuel mixture.

8.24.2 Magneto ignition system

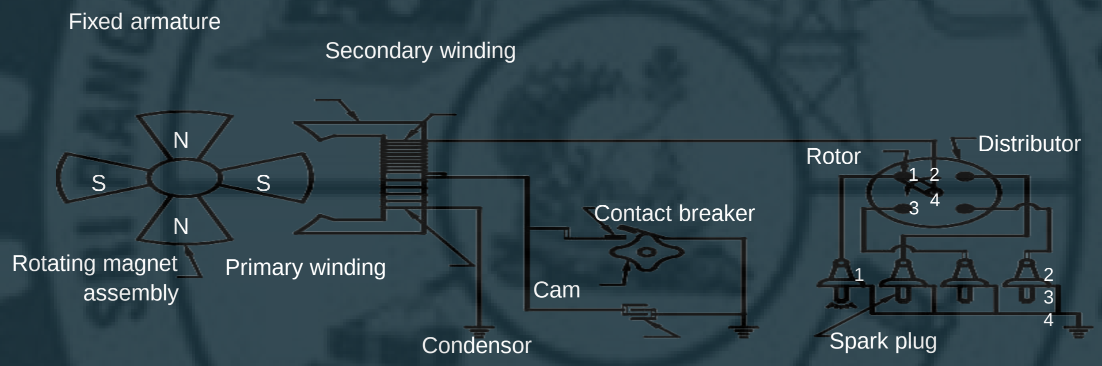


Fig.8.24 Magneto ignition system

Magneto ignition system is generally employed in light duty petrol engines such as motor cycles, scooters, etc. The wiring diagram of magneto ignition system for a four cylinder petrol engine is shown in the figure.

Construction

This system consists of a magneto, ignition switch, contact breaker, condenser, distributors and spark plugs. The magneto consists of a fixed armature and a rotating magnet assembly. The armature contains primary and secondary windings. The magnet is placed on the outer rim of the fly wheel.

The circuit of this system can be divided into *primary circuit* and *secondary circuit*. The primary circuit consists of battery, primary winding, condenser and contact breaker. The secondary circuit consists of secondary coil, distributor and spark plug. The functions of all other parts are similar to the coil ignition system.

Working principle

The ignition switch is switched on and the engine is cranked. The cranking of the engine opens and closes the contact breaker points through the cam.

When the contact breaker points are closed, the current flows from the battery to the contact breaker through the switch and primary winding. This current sets up a magnetic field around the primary winding of ignition coil. When the primary current is at the highest peak, the contact breaker points are opened by the cam. The magnetic field set up in the primary winding is collapsed suddenly. Due to this, a high voltage (about 10,000 Volts) is generated in the secondary winding of the ignition coil. This high voltage is supplied to the rotor of the distributor. The rotor distributes the high voltage to various spark plugs in the sequence of firing order of the engine. When this high voltage tries to escape through the spark plug gap, an electric spark is produced. This spark ignites the air–fuel mixture.

8.24.3 Electronic ignition system

In this system, contact breaker points are replaced by the magnetic pickup and reluctor. This eliminates the defects due to contact breaker points. The schematic diagram of an electronic ignition system is shown in the figure.

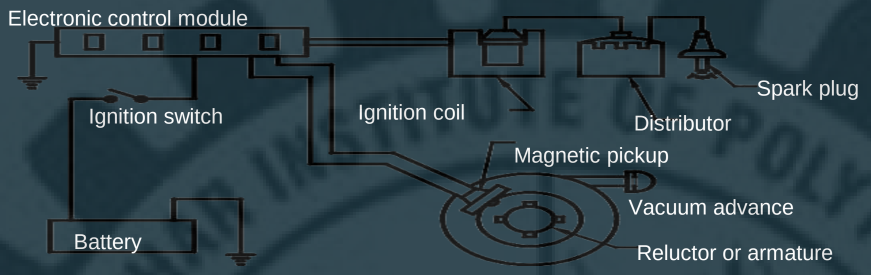


Fig.8.25 Electronic ignition system

Construction

This system consists of a battery, ignition switch, electronic control module, magnetic pickup, reluctor or armature, ignition coil, distributor and spark plugs. A number of metal tips are provided on the reluctor according to the number of cylinders of the engine. A permanent magnet is carried by the distributor. The reluctor provides a path for the magnetic lines from this magnet.

Working principle

The ignition switch is switched on and the engine is cranked. When the reluctor passes the pick up coil, an electric pulse is generated and magnetic field is induced. This causes a magnetic field in the primary winding. This small current triggers the electronic control module. This control module stops the flow of battery current to the ignition coil. The magnetic field set up in the primary winding is collapsed suddenly. Due to this, a high voltage is generated in the secondary winding. This high voltage is supplied to the distributor. The distributor distributes the high voltage to various spark plugs in the sequence of firing order of the engine. When this high voltage tries to escape through the spark plug gap, an electric spark is produced. This spark ignites the air–fuel mixture.

8.25 Governing of internal combustion engine

Governing is the process of regulating the fuel supply according to the load condition so that to run the engine almost at constant speed. The device used to regulate the fuel supply is known as governor. The following are the different methods of governing an internal combustion engines:

a) Quantity governing
b) Quality governing
c) Hit and miss governing

a) ***Quantity governing :*** In this method, the quantity of air–fuel mixture entering into the engine cylinder is varied. The composition of the air–fuel mixture remains constant when the load varies. In petrol engines, the control is obtained by a throttle valve in the carburettor. In automobiles, the throttle valve is operated by the accelerator pedal through links.

b) ***Quality governing :*** Quality governing is commonly adopted in high speed diesel engines. In this type of governing, the composition of air–fuel mixture is changed according to the variation is load. The air flow rate remains constant. The variation in fuel supply is obtained by the following methods:

(1) Adjusting the effective stroke of the fuel injection pump
(2) By–passing a part of the fuel to the reservoir
(3) Delaying the closure of the suction valve of the fuel injection pump.

c) Hit and miss governing : In this method, an explosion is omitted when the speed of the engine increases above the normal speed i.e. one power stroke is missed. The strength of the air–fuel mixture is not varied. In gas engines, the centrifugal governor closes the inlet valve. In diesel engines, the governor makes the fuel pump out of action. No fuel will be supplied and hence there will be no power stroke.

8.26 Cooling system of I.C engines

The temperature of the burning gases in the engine cylinder is about 2000 to 2500°C. This heat is absorbed by the engine components like cylinder head, cylinder walls, piston and valves. The heating of these parts may cause the following.

1. The strength of piston and cylinder body may be reduced.
2. The engine valves may twist due to overheating.
3. The lubricating oil may decompose and become gummy. It also gives carbon deposits.
4. It causes thermal stresses in the engine parts, which may lead to their distortion.
5. Pre–ignition may occur due to the over heating of spark plug.
6. It reduces the volumetric efficiency of the engine.

In order to avoid the effects of over heating, it is necessary to provide a cooling system. However, a cooling system should remove only about 30% of the heat generated by the combustion of fuel.

The following two methods of cooling are generally used in internal combustion engines.

1) Air cooling or direct cooling
2) Water cooling or indirect cooling

8.26.1 Air cooling

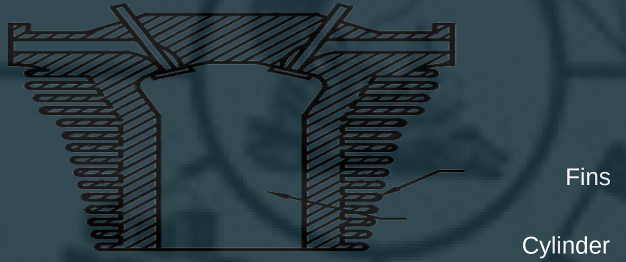


Fig.8.26 Air cooling

Air cooling is used in small engines like, air craft engines, engines used in scooters, motor cycles, etc. In air cooling system, the air is allowed to circulate around the cylinder block and cylinder head. Radiating fins are provided on the outer surface of the cylinder block and cylinder head. This increases the heat radiating surface. As more air comes in contact with the cylinder, the heat is removed efficiently. The high velocity of air required for cooling is obtained by the forward motion of the engine itself. Air circulating fan is provided in stationary engines.

Advantages of air cooling

1) The design of air cooling system is much simpler.
2) Lighter in weight.
3) The system is free from leakage and freezing of water.
4) Less space is sufficient.
5) This is very much useful in water scarcity areas.
6) The amount of cooling air required is less.

Disadvantages

1) This system is limited to small engines.
2) The engine parts are not uniformly cooled.
3) Air cooled engine produces loud noise.
4) Separate circulating fan is needed in stationary engines.

8.26.2 Water cooling

Water cooling is used in light and heavy vehicles such as automobiles, buses, lorries, trucks, etc. In water cooling system, the water is allowed to circulate around the cylinder block and cylinder head to carry the heat. It consists of radiator, fan, water pump, water jacket, thermostat valve, radiator shutters, etc.

The water pump driven by the engine draws cold water from the radiator. The cold water is forced to circulate through water jackets of cylinder block and cylinder head. Thus, the circulating water cools the engine parts by absorbing heat. Then the water enters the radiator top and flows from top to bottom. While flowing through radiator tubes, the heat of water is transmitted to the air drawn by a fan through radiator. Then the water is cooled and recirculated.

However, the temperature of the cooling water should not fall below 75°C. A thermostat valve is provided between the engine and the radiator top to control the temperature of the cooling water. The valve remains open under normal operating temperatures. When the temperature falls below normal, the valve is closed to bypass the water. Thus cooling of water is automatically ceased.

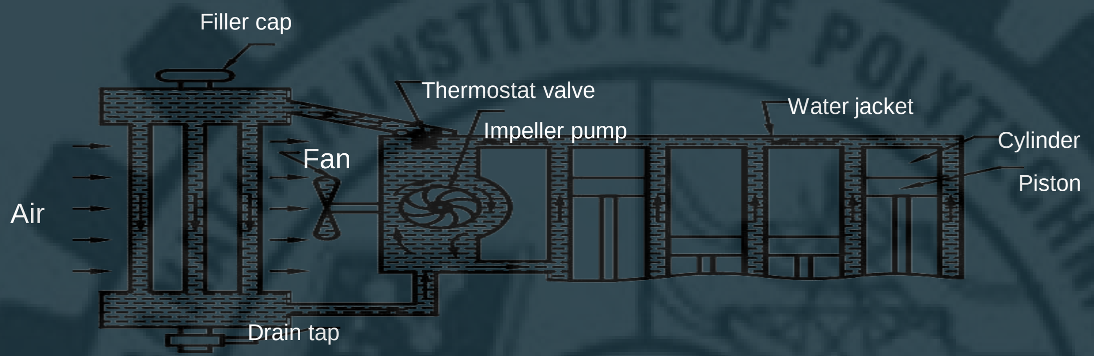


Fig.8.27 Water cooling system

When the heat of the engine is more, the radiator shutters are opened to allow more air to flow through the radiator. Thus, the rate of cooling is increased. A drain tap is provided at the bottom of the radiator to remove the water periodically.

Advantages of water cooling

1) More efficient cooling can be obtained. Hence, efficiency of the engine is more.
2) Higher compression ratio is permitted.
3) The engine parts are uniformly cooled.
4) Water cooled engines can be installed anywhere in the vehicle.

Disadvantages

1) Water cooling system is heavier in weight.
2) More maintenance is required.
3) A slight leakage of water may stop the engine.
4) Freezing of water causes trouble during cold weather.
5) Water circulating pump and radiator pump consume power.

8.27 Comparison of air cooling and water cooling system

	Air cooling system	Water cooling system
1.	Engine design is simple	Engine design is not much simple
2.	Weight is less	Weight is more
3.	No leakage problems	Leakage of water may occurs
4.	No risk of freezing of water in cold climates	Freezing of water in cold climate may cause trouble
5.	Less maintenance is sufficient	More maintenance is required
6.	Requires less space	More space is required
7.	No danger occurs due to the damage in cooling system	A small damage in the cooling system may cause danger
8.	The cost for cooling system is less	The cost for cooling system is more
9.	Cooling is not so efficient	Cooling is more efficient
10.	Engine parts are not uniformly heated	Engine parts are uniformly heated
11.	Higher compression ratio is not permitted	Higher compression ratio is permitted
12.	It is used in light duty vehicles	It is used in heavy duty vehicles

8.28 Lubrication of I.C engines

In an internal combustion engine, moving parts and rotating parts rub against each other and frictional force is developed. Due to this frictional force, heat is generated and the engine parts wear quickly. Also, power is lost due to friction. Lubricants are introduced between moving and rotating parts to reduce heat loss wear and tear.

8.28.1 Purposes of lubrication (or)

Functions of lubrication in I.C engines

1. To reduce friction between moving parts
2. To reduce wear and tear of the moving parts
3. To reduce the power loss due to friction
4. To dissipate the heat generated from the moving parts
5. To provide cushioning effect against the shocks of the engines
6. To clean the moving parts by dissolving the impurities during its circulation
7. To provide an effective seal against high pressure gases in the cylinder from leaking out
8. To reduce the noise while the moving parts rub against each other
9. To reduce the corrosion and erosion of moving parts

2. Properties of lubricants

The important properties of lubricants are explained below:

1) ***Viscosity :*** Viscosity is the resistance offered to the flow of the lubricant. Viscosity of the oil decreases with the increase in temperature. Viscosity of the lubricating oil should be within a specified range even at the highest operating temperature of the bearings. If too thick oil is used, it will lead to power loss, and excessive wear and tear of the part. If the oil is too thin, it cannot lubricate properly and lead to rapid wear of moving parts.

2) ***Oiliness:*** It is the property of an oil to spread and adhere itself firmly with the bearing surfaces. Oiliness of the lubricating oil should be high for better lubrication.

3) ***Flash and fire point :*** Flash point of an oil is the minimum temperature at which it gives off enough vapour so that a momentary flame is obtained when a flame is brought near the oil surface. Fire point is the minimum temperature at which an oil continuously burns. Fire point is always greater than the flash point. The flash point of the lubricating oil should be higher than the operating temperature of the bearing.

4) ***Delegency :*** The lubricating oil should carry away small impurities to keep the interior of the engine clean. This property of lubricating oil is known as delegency.

5) ***Demulsibility (water separation) :*** The lubricating oil should not form an emulsion when brought in contact with water. The property of resisting emulsification is known as demulsibility.

6) ***Foaming :*** It is the condition in which small air bubbles are present in the oil. This will reduce mass flow or oil and also increase oxidation. Hence the lubricating oil should be free from foaming problems.

7) ***Corrosiveness :*** The lubricating oil should prevent the engine parts from corrosion and it should not contain sulphur.

8.29 Methods of lubrication

The following are the methods of lubrication systems are used in internal combustion engines.

1. Petroil lubrication system or mist lubrication system.
2. Wet sump lubrication system
   a) Gravity lubrication system
   b) Splash lubrication system
   c) Pressure lubrication system
   d) Semi–pressure lubrication system
3. Dry sump lubrication system

8.29.1 Splash lubrication system

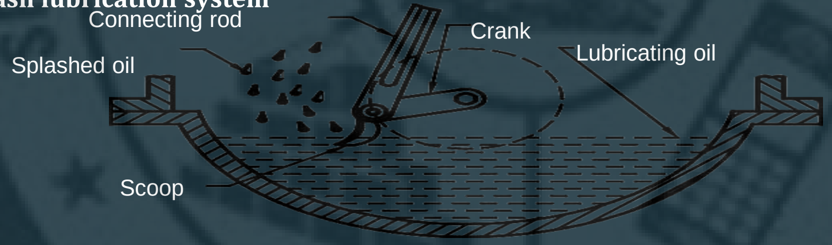


Fig.8.28 Splash lubrication system

This lubrication system is employed in single cylinder stationary internal combustion engines. In this system, the lubricating oil is filled in the sump at the bottom of the crank case. Scoops are attached to the big end of the connecting rod.

When the piston is at the bottom of its stroke, the big end of the connecting rod, crank pin and scoop dip into the oil. As the crank shaft rotates, the scoop picks up the lubricating oil from the sump and the surplus oil is splashed over the engine parts in the form of droplets by centrifugal action. Splashed oil droplets settle on the surface of the piston, cylinder walls, cam shaft and crank shaft bearings, etc. and lubricate these parts. The splashed oil is drained back to the sump after lubricating.

8.29.2 Pressure lubricating system (or) Forced lubrication system

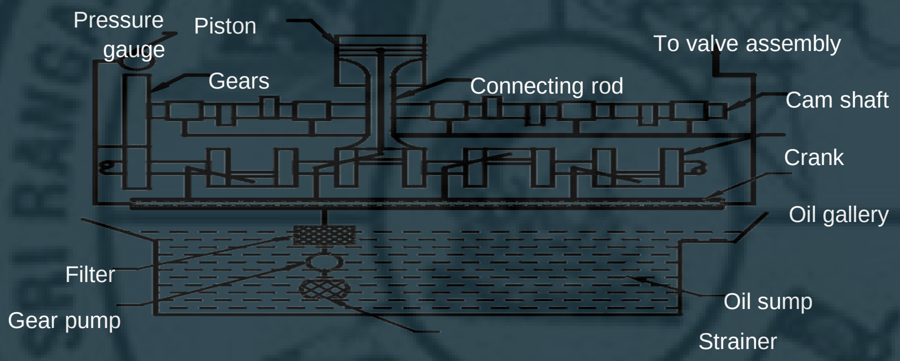


Fig.8.29 Pressure lubrication system

This system is used in light engines like automobile engines. In this method, the lubricating oil is forced under pressure for efficient lubrication. The line diagram of pressure lubrication system is shown in the figure. It consists of oil sump, oil pump, oil gallery, oil filter, pressure relief valve, pressure gauges and oil dip stick.

The oil pump (gear pump) is submerged in the lubricating oil and it is driven by the cam shaft. The gear pump supplies oil to the oil gallery with high pressure through filters. From the oil gallery, the oil is distributed under pressure to the different parts of the engine through oil tubes. Separate oil tubes carry oil for lubricating big end bearings, timing gears, crank shaft, cam shaft, valve assembly, etc. Oil from the gallery is supplied to the crank shaft bearing. The oil flows to the connecting rod big end bearing through the diagonally drilled hole in the crank shaft. A through hole is drilled at the centre of the connecting rod. The oil from the big end bearings flows to the small end bearings through the hole and lubricate it.

The excess oil is drained back into the oil sump. The delivery pressure of the oil is controlled by relief valve. A pressure gauge indicates the oil pressure in the system. An oil dip stick is provided to measure the oil level in the sump.

8.30 Oil pumps

The function of an oil pump is to supply lubricating oil under pressure to the bearings and the various parts of the engine to be lubricated. It is located inside the crankcase and submerged in the oil sump. It is driven by the camshaft through a worm or spiral gear. The commonly used oil pumps are :

1) Gear pump 2) Rotor pump.

8.30.1 Gear pump

Gear pump consists of two spur gears meshed together. The driver gear is driven by the camshaft. The two gears have a small clearance with the casing. The gears are adjusted so that they form a fluid–tight joint when they mesh together.

Working principle

The gear pump is submerged in the oil in the crankcase. When the gears rotate, the oil is tapped between their teeth and discharged through the outlet. The gears gradually build up sufficient pressure to force the oil through the delivery pipe.

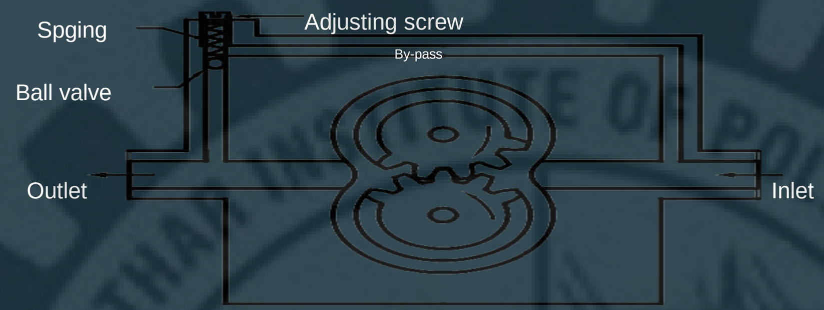


Fig.8.30 Gear pump

A pressure relief valve is provided to relieve excessive pressure caused by high engine speeds. When the oil pressure exceeds the specified limit, the ball in the relief valve is lifted off its seat against the spring force and the oil is forced through the by pass. An adjusting screw is provided to set the working pressure of the pump.

8.30.2 Rotor pump

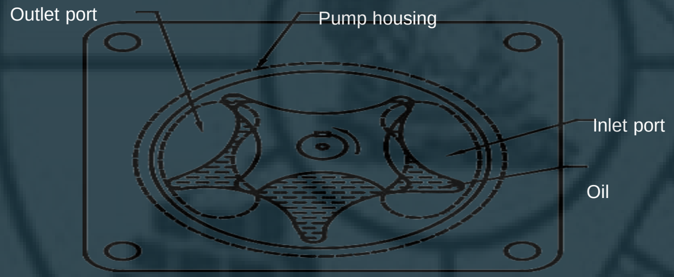


Fig.8.31 Rotor pump

Rotor pump consists of inner rotor, outer rotor, inlet and outlet ports. The two rotors mesh internally. The inner rotor has a number of lobes (teeth) one less than that on the outer rotor. The inner rotor

2) Full flow system : In this system, the entire oil passes through the filter before it is supplied to the engine part. A spring loaded relief valve is provided in the filter in addition to the main relief valve. when the filter is blocked, the by–pass valve diverts the unfiltered oil to the engine parts. As the entire oil passes through the filter, the faltering elements used are comparatively coarser. The commonly used filtering elements are wire gauze, cotton, felt, paper, plastic–impregnated paper, etc. This type of system is widely used in automobiles nowadays.

32. Supercharging of internal combustion engines

Supercharging is forcing of air–fuel mixture or air alone into the engine cylinder during the suction stroke with a pressure greater than the atmospheric pressure. The density of air–fuel mixture or air entered into the engine cylinder is increased by supercharging. This is done by a compressor known as supercharger or blower. As it increases the power output of the engine, it is also called as boosting.

1. Effects or advantages of supercharging

1) The power output of the engine is increased.
2) It provides better mixing of air and fuel.
3) It gives better vaporization of fuel and thus increases the temperature of the charge.
4) It reduces the possibility of knocking in C.I engines.
5) Supercharged engines produces greater output even at high altitude.

8.32.2 Applications of supercharging

1) it is used in air crafts and stationary installations in mountains to maintain a constant power output even at higher altitudes.
2) It is used in locomotives and marine engine to reduce the size of the engine so as to fit into a limited space.
3) Supercharging reduces weight of the engine and increases the volumetric efficiency. Hence it is used in racing car engines.
4) It is used to increase the power of an existing engine when more power is required.

Unit – IV FUELS AND COMBUSTION OF FUELS

1. Introduction

A fuel may be defined as a substance which produces a large amount of heat when burning with oxygen in the atmospheric air. The amount of heat generated is known as calorific value of the fuel.

1. Classification of fuels

The fuels may be classified as follows:

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels

Each of these fuels may be further subdivided into

(a) Natural fuels (b) Prepared fuels

1. Solid fuels

Natural solid fuels are readily available in nature. Examples of such fuels include *wood, peat* (mixture of water and decayed vegetable matter), *lignite, bituminous coal, anthracite coal,* etc.

Wood consists of mainly carbon and hydrogen. It is converted into coal when burnt in the absence of air. It is used in places where large amount of waste wood is available. Peat is not widely used because it has a large amount of water content. Lignite is an intermediate variety between bituminous coal and peat. It contains more moisture and lower calorific value. Bituminous coal contains little moisture and higher carbon. This is widely used for power generation in thermal power plants.

Anthracite coal is the final stage of coal formation. It is mostly used for domestic purposes because of its smokeless combustion. It has high calorific value.

The examples of prepared solid fuels include *charcoal, coke, briquetted coal, pulverized coal, etc*.

Charcoal is prepared by the dry distillation of wood. It is a good prepared solid fuel and is used for various metallurgical processes. Coke is produced when coal is strongly heated continuously for 42 to 48 hours in the absence of air in a closed vessel. It has high carbon content and has a higher calorific value than coal. Briquetted coal is produced form the finely ground coal by moulding under pressure. Pulverized coal is obtained by pulverizing the low grade fuels.

2. Liquid fuels

Liquid fuels are obtained from natural petroleum or crude oil. The liquid fuels consist of hydrocarbons. They are mostly used in internal combustion engines. The important liquid fuels are
gasoline (petrol), paraffin, diesel, oil, etc.

Advantages of liquid fuels:

- Higher calorific value
- Lower storage space required
- Better control of consumption by using valves
- Better cleanliness and freedom from dust
- Easy handling and transportation
- Higher efficiency

Disadvantages

- Higher cost
- More risk of fire
- Requires costly containers for storage

3. Gaseous fuels

The natural gas is found in or near the petroleum fields, under the earth's surface. It consists of *methane* (CH_4), *ethane* (C_2H_6), *carbon dioxide* (CO_2) *and carbon monoxide* (*CO*).

The important prepared gases are *coal gas, producer gas, water gas, mond gas, blast furnace gas, coke over gas, etc.* Coal gas is obtained by the carbonization of coal. It is largely used for domestic lighting and heating. Producer gas is obtained by the partial combustion of coal, coke, anthracite coal or charcoal in a mixed air–steam blast. It is used in furnaces and for power generation. Water gas is a mixture of hydrogen and carbon monoxide. It is produced by passing steam over incandescent coke. The water gas is used in furnaces and for welding.

Mond gas is produced by passing air and a large amount of steam over waste coal. It is used for power generation and heating. Blast furnace gas is a by–product in the production of pig iron in the blast furnace. It is used for power generation in gas engines, foe steam raising in boilers and for preheating the blast for furnace. Coke over gas is a by–product from coke oven. It is obtained by the carbonization of bituminous coal. It is used for industrial heating and power generation.

Advantages of gaseous fuels

- The gaseous fuels undergo complete combustion with minimum air supply.
- They do not produce ash or smoke.
- They are free from solid and liquid impurities.
- The high temperature can be obtained at a moderate cost.
- The supply of gaseous fuel can be accurately controlled.
- Gas firing system is very clean.

Disadvantages

- Gaseous fuels are easily inflammable
- The require large storage capacity

3. Requirements of a good fuel

The following are the important requirements of a good fuel:

A good fuel should

- have high calorific value
- have a low ignition temperature
- not produce any harmful gases.
- burn freely with high efficiency, once it is ignited.
- produce less smoke and gases,
- be economical
- be easily stored and transported

7.4 Composition of fuels

Solid fuel consists of mainly carbon and hydrogen. They also contain oxygen, nitrogen and mineral substances in various compositions. The chemical composition of coal, coke, peat, etc can be determined by ***proximate*** and ***ultimate analysis***.

a) Proximate analysis

Proximate analysis is carried out to determine the following in the fuel:

(1) Moisture content (2) Volatile matter

(3) Fixed carbon and (4) Ash

(1) To determine moisture content : A known mass of fuel (m_f) is heated to about 120 ^oC to remove water by evaporation. Final mass of the fuel (m_e) is estimated. The difference between the initial and final mass gives the amount of moisture content.

Mass of moisture, $m_m = m_f - m_e$

The percentage of moisture in the fuel is calculated as:

$$m_m\% = \frac{m_m}{m_f} \times 100$$

(2) To determine the volatile matter : A known mass of fuel (m_f) is kept in an air tight crucible and heated for 7 minutes at about 960 ^oC. The volatile matter along with moisture is removed from the fuel. The final mass of the fuel (m_e) is estimated. The mass of volatile matter is determined as follows:

Mass of volatile matter, $m_v = m_f - m_e$

The percentage of volatile matter in the fuel is calculated as:

$$m_v\% = \frac{m_v}{m_f} \times 100$$

(3) To determine the ash content : A known mass of fuel (m_f) is taken and is burnt at 730 ^oC in the presence of oxygen. All combustible matter burns at this temperature leaving the ash as residue. Final mass of the ash is (m_{ash}) is estimated.

The percentage of ash contents is calculated as:

$$m_{ash}\% = \frac{m_{ash}}{m_f} \times 100$$

(4) To determine the fixed carbon : The fixed carbon is determined as follows:

Mass of carbon, $m_c = m_f - m_m - m_v - m_{ash}$

The percentage of fixed carbon is determined as follows:

$$m_c\% = 100 - m_m\% - m_v\% - m_{ash}\%$$

b) Ultimate analysis

The ultimate analysis is carried out to determine the percentages of the ultimate constituents of the following:

(1) Carbon	(2) Hydrogen	(3) Oxygen
(4) Sulphur	(5) Nitrogen	(6) Ash

(1) To determine carbon and hydrogen percentage : A sample of fuel is burnt in a oxidised atmosphere. Carbon dioxide and water vapours are produced by burning of fuel. The masses of carbon dioxide are determined. The carbon dioxide is absorbed in a solution of potassium hydroxide for estimating the mass. Water vapours are collected in chloride tube.

(1) To determine ash percentage : A known sample of fuel is burnt at 730 ^{o}C in the in the presence of oxygen. All combustible matter burns at this temperature leaving the ash as residue. The mass of the ash is estimated.

(1) To determine the nitrogen and sulphur percentage : This is estimated by complex chemical analysis on different samples of fuel.

(1) To determine the oxygen percentage : The percentage of oxygen is determined as follows:

Percentage of oxygen = 100 − Sum of percentages of remaining constituents in the fuel.

5. Elements and compounds

An element is a basic substance which cannot be broken to form another substance. The elements may be in solid, liquid or gaseous state. A compound is a substance formed by chemically combining two or more elements so that the properties of the compound entirely differ from those of the individual elements.

Example: Sodium chloride (Common salt) is a compound which is formed by the chemical combination of two elements sodium and chlorine.

5. Atom and molecule

An *atom* is the smallest particle of an element. It retains the properties of that element. The mass of an atom varies from element to element. Atomic mass or atomic weight is the relative measure of an atom.

A *molecule* is the smallest quantity of substance which retains the properties of the compound. Molecular weight is the relative measure of a molecule. The atomic weight and molecular weight of some important substances are tabulated below:

Substance	Symbol	Atomic weight (Atomic mass)	Molecular Weight
Elements Carbon Hydrogen Nitrogen Oxygen Sulphur	C H_2 N_2 O_2 S	12 1 (1.008) 14 16 32	12 2 28 32 32
Compounds Carbon dioxide Carbon monoxide Water vapour Sulphur dioxide Methane	CO_2 CO H_2O SO_2 CH_4	– – – – –	12 + 32 = 44 12 + 16 = 28 2 + 16 = 18 32 + 32 = 64 12 + 4 = 16

Total Oxygen required $= \frac{8}{3}C + 8H_2 + S$ kg

Oxygen available in the fuel $= O_2$ kg.

$\therefore$ Net oxygen required for the combustion of the fuel $= \frac{8}{3}C + 8H_2 + S - O_2$ kg

Air required for 23 kg of oxygen = 100 kg

Air required for $\left[\frac{8}{3}C + 8H_2 + S - O_2\right]$ kg of oxygen

$$m_{min} = \frac{100}{23}\left[\frac{8}{3}C + 8H_2 + S - O_2\right] \text{kg.}$$

7.11 Excess air

The theoretical air supplied may not be sufficient for the complete combustion of the fuel. In actual practice, the amount of air supplied is always in excess than the theoretical air required. The amount of excess air supplied depends on the quantity of fuel to be burnt, rate of combustion, method of firing, etc. Generally 25% to 50% excess air used. If excess air is supplied,

Total air supplied = Theoretical (minimum) air + Excess air

$$m_{total} = m_{min} + m_{ex}$$

Mass of excess air : The mass of excess air supplied can be determined by the mass of unused oxygen available in the flue gases.

$\frac{100}{23}$ kg of air is required for 1 kg of oxygen.

$\therefore$ Excess air supplied, $m_{ex} = \frac{100}{23} \times$ **Mass of O_2 in flue gases.**

7.12 Product of combustion

The products of combustion during the combustion of a fuel can be estimated if the percentage of constituents of the fuel are known.

Air required for 21 m^3 of oxygen = 100 m^3

Air required for $[0.5CO + 0.5H_2 + 3CH_4 + 3C_2H_4 - O_2]$ m^3 of oxygen

$$= \frac{100}{21}[0.5CO + 0.5H_2 + 3CH_4 + 3C_2H_4 - O_2]$$

∴ Minimum volume of air required,

$$V_{air} = \frac{100}{21}[0.5CO + 0.5H_2 + 3CH_4 + 3C_2H_4 - O_2]$$

14. Volumetric and gravimetric analysis

The analysis of the composition of a mixture of gases based on volume is known as *volumetric analysis*. This gives the percentage by volume of each of the constituents of a gaseous fuel.

The analysis of a mixture of gases based on mass or weight is known as *gravimetric analysis*. This gives percentage by mass or weight of each of the constituents of a gaseous fuel.

14. Conversion of volumetric to gravimetric (mass) analysis

The conversion of volumetric to gravimetric analysis involves the following steps:

(1) The percentage volume V and the molecular weight M of each constituent are noted.

(2) The mass of each constituent is found out by multiplying the volume and its molecular weight ($m = V \times M$)

(3) Total mass of the mixture of gases is found out by adding the individual mass of each constituents. ($\sum m = m_1 + m_2 + \ldots$)

(4) The percentage by mass of each constituents is calculated by dividing the mass of the constituent by total mass of the gas.

$$\% \text{ mass} = \frac{m}{\sum m}$$

7.16 Conversion of gravimetric (mass) analysis into volumetric analysis

The conversion of gravimetric to volumetric analysis involves the following steps:

(1) The percentage mass m and the molecular weight M of each constituent are noted.

(2) The volume of each constituent is found out by dividing the mass of the constituent by its molecular weight ($V = \frac{m}{M}$)

(3) Total volume of the mixture of gases is found out by adding the individual volume of each constituents. ($\sum V = V_1 + V_2 + \ldots$)

(4) The percentage by volume of each constituents is calculated by dividing the volume of the constituent by total volume of the gas.

$$\%\ \text{volume} = \frac{V}{\sum V}$$

7.17 Mass of air actually supplied and air fuel ratio

The air−fuel ratio in volumetric analysis is given by,

$$m_{tot} = \frac{\text{Air}}{\text{Fuel}} = 3.03C\left[\frac{N_2}{CO_2 + CO}\right] \text{ kg / kg of fuel}$$

where, C = Mass of carbon in 1 kg of fuel

N_2 = Percentage by volume of N_2 in flue gases

CO_2 = Percentage by volume of CO_2 in flue gases

CO = Percentage by volume of CO in flue gases

The air−fuel ratio in gravimetric analysis is given by,

$$m_{tot} = \frac{\text{Air}}{\text{Fuel}} = \frac{100 \times N_2 \times C}{21CO_2 + 33CO} \text{ kg / kg of fuel}$$

where, C = Mass of carbon in 1 kg of fuel

N_2 = Percentage by mass of N_2 in flue gases

CO_2 = Percentage by mass of CO_2 in flue gases

CO = Percentage by mass of CO in flue gases

7.18 Calorific value (CV)

The calorific value of a fuel is defined as the amount of heat liberated by the complete combustion of unit quantity (1 kg in case of solid and liquid fuel, and 1 m^3 in case of gaseous fuels) of a fuel. It is expressed as kJ/kg for liquid and solid fuels, and kJ/ m^3 for gaseous fuels.

(a) Gross or Higher Calorific Value (HCV)

It is defined as the amount of heat obtained by the complete combustion of unit mass (or unit volume) of a fuel, when the products of combustion are cooled down to the temperature of the air (15 °C) supplied.

7.20 Experimental determination of calorific value

Calorimeters are used to determine the calorific value of any fuel. The generally used calorimeters are :

1) Bomb calorimeter (for solid and liquid fuels)
2) Junker's calorimeter (for gaseous fuels)
3) Boy's calorimeter (for gaseous fuels)

1) Bomb calorimeter

This calorimeter is used to determine the calorific value of solid and liquid fuels.

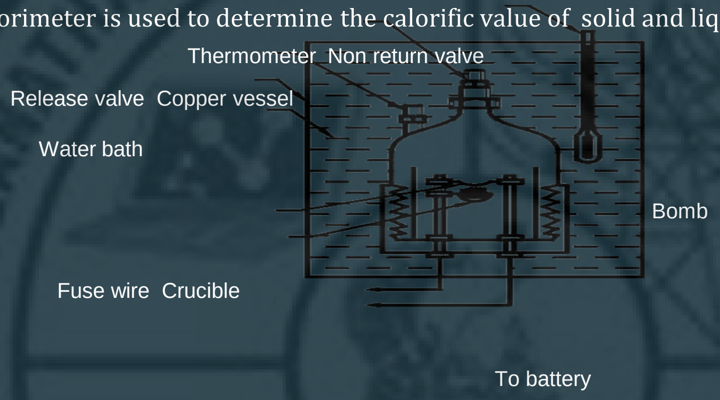


Fig. 7.1 Bomb calorimeter

Construction:

The schematic arrangement of bomb calorimeter is shown in the figure. It consists of a bomb made of thick walled stainless steel. It is designed so as to withstand high pressure, heat and corrosion. A crucible is provided inside the bomb to place the fuel. The oxygen required to burn the fuel is supplied to the bomb through a non−return valve. A pressure release valve is provided to discharge the burnt gases. Two guide rods are provided at the bottom. The crucible is supported by one of the guide rods. The guide rods are connected with a fuse wire made of platinum of nichrome. The other ends of fuse wire are connected to a battery. The fuel can be ignited by the heat generated in the fuse wire when high voltage current is passed through the wire. The bomb is placed in a water bath containing a known quantity of water. A stirrer is also provided.

Procedure:

A known mass of a fuel sample is placed in the crucible.
Oxygen is supplied through the non−return valve till the pressure inside the bomb rises to 30 atm. Then, the bomb is completely submerged in a known quantity (m_w) of water in a large copper vessel. The vessel is placed inside a large insulated copper vessel to reduce the heat losses due to radiation. When a steady temperature (T_1) is reached, the fuse wire is heated up by passing electricity. The fuel is ignited and burnt completely. The heat released during the combustion of the fuel is absorbed by the surrounding water and apparatus. The final temperature of water (T_2) is noted.

Let,

m_f	=	Mass of fuel burnt
m_w	=	Mass of water in calorimeter
m_c	=	Mass of calorimeter apparatus
HCV	=	Higher calorific value of the fuel
C_{pw}	=	Specific heat capacity of water
C_{pc}	=	Specific heat capacity of calorimeter
T_1	=	Initial temperature of water and calorimeter
T_2	=	Final temperature of water and calorimeter
H_2	=	Mass of hydrogen present in 1 kg of fuel

Heat liberated by the fuel, $Q_f = m_f.HCV$

Heat absorbed by the water, $Q_w = m_w.C_{pw}.(T_2 - T_1)$

Heat absorbed by the calorimeter, $Q_c = m_c.C_{pc}.(T_2 - T_1)$

$$Q_f = Q_w + Q_c$$

$$m_f.HCV = m_w.C_{pw}.(T_2 - T_1) + m_c.C_{pc}.(T_2 - T_1)$$

$$\therefore HCV = \frac{m_w.C_{pw}.(T_2 - T_1) + m_c.C_{pc}.(T_2 - T_1)}{m_f}$$

Water equivalent of apparatus, $m_e = \frac{m_c.C_{pc}}{C_{pw}}$

$$\therefore HCV = \frac{(m_w + m_e).C_{pw}.(T_2 - T_1)}{m_f}$$

To compensate the loss of heat due to radiation, a cooling correction is added to the observed temperature rise.

Corrected temp. rise = Observed temp. rise + Cooling correction.

$$(T_2 - T_1)_c = (T_1 - T_1) + T_c$$

The corrected temperature rise is substituted in the above expression to estimate the *HCV* of the fuel.

The lower calorific value (LCV) is calculated from the amount of moisture (m_m) and hydrogen present in the fuel.

$$LCV = HCV - (9\,H_2 + m_m) \times 2466$$

2) Junker's gas calorimeter

This calorimeter is used to find out the calorific value of gaseous fuels.

Construction:

It consists of a cylindrical chamber with vertical tubes. A burner is provided at the bottom of the chamber to burn the gas. The hot burnt gases pass to the top of the burner and then descend through small metal tubes. These tubes are surrounded by water. Water enters through bottom of the chamber and leaves at the top. A pressure regulator is provided to control the pressure of the gas entering the gas meter. A pressure gauge and a thermometer are also provided.

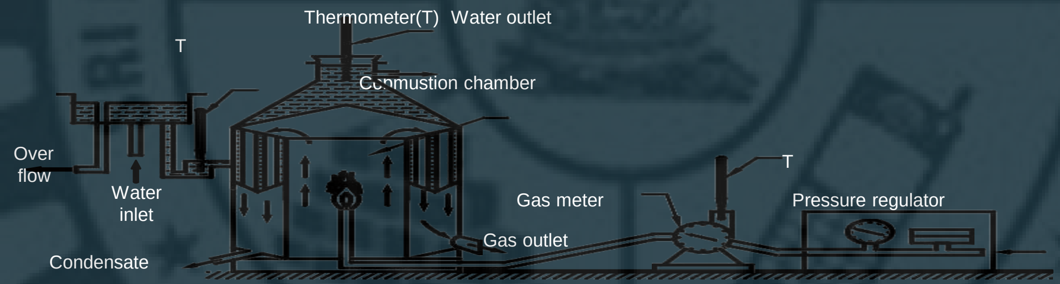


Fig.7.2 Junker's gas calorimeter

Procedure:

The gaseous fuel is passed through the burner. The gas is burnt under steady uniform conditions until the equilibrium condition is reached. The volume of the gas (V) passing through the calorimeter is measure by the gas meter. The temperature of the gas (T) is noted. The pressure of the gas (p_g) and the barometric pressure (p_b) are noted. The inlet temperature (T_1) and outlet temperature (T_2) of the cooling water are noted. The mass of the cooling water (m_w) is measured. The amount of condensate (m_s) is measured by collecting it in a small graduated vessel.

Let,

p_s = Standard pressure

T_s = Standard temperature

V_s = Volume of the gas burnt reduced to S.T.P

The calorific value of gaseous fuels is generally expression kJ/ m^3 of the gas at S.T.P conditions.

The volume of gas reduce to S.T.P conditions is calculated using gas equation.

By gas equation,

$$\frac{p_s.V_s}{T_s} = \frac{p.V}{T} \; ; \; \therefore V_s = \frac{p.V}{T} \times \frac{T_s}{p_s}$$

Heat released by the fuel, $Q_f = HCV \times V_s$

Heat carried by the water, $Q_w = m_w.C_{pw}.(T_2 - T_1)$

Heat released by the fuel = Heat carried by the water

$$HCV \times V_s = m_w.C_{pw}.(T_2 - T_1)$$

$$\therefore \mathbf{HCV} = \frac{m_w.C_{pw}.(T_2 - T_1)}{V_s}$$

The lower calorific value is determined from the amount of condensate collected.

$$\mathbf{LCV} = \mathbf{HCV} - \left[\frac{m_s}{V_s} \times 2466\right]$$

7.21 Orsat apparatus for flue gas analysis

The constituents of the flue gases are determined for checking the combustion efficiency of boilers. Orsat apparatus is used to carry out the flue gas analysis.

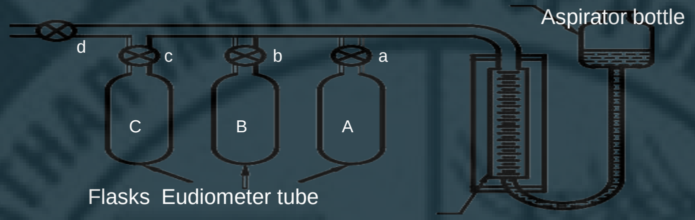


Fig.7.3 Orsat apparatus

Construction:

Orsat apparatus consists of a graduate measuring glass tube, called as eudiometer, and three flasks *A*, *B* and *C*. An aspirator bottle containing water is connected to the bottom of the eudiometer tube by means of rubber tube. It can be moved up and down for producing a suction or pressure effect on the sample of the flue gas.

The flask *A* contains caustic soda (NaOH) and is used to absorb carbon dioxide in the sample of the flue gas. The flask *B* contains caustic soda and pyrogallic acid, which absorbs oxygen from the sample of the flue gas. The flask *C* contains a solution of cuprous chloride (Cu_2Cl_2) in hydrochloric acid (HCl). It is used to

absorb carbon monoxide (CO) from the sample of the flue gas. Each of the three flasks has stop cock '*a*', '*b*', and '*c*' respectively and a three−way cock '*d*' which can be opened to either atmosphere or flue gas.

Procedure :

The stop cocks (*a*, *b* and *c*) are closed. The three−way cock is opened and 100 c m^3 of flue gas is sucked into the measuring glass. Then the three−way cock is closed. The level of the aspirator bottle is adjusted and the flue gas is forced in to flask *A* by opening the cock 'a'. The flue gas is allowed to remain in the flask A for sometime. The chemical in the flask A absorbs carbon dioxide. Then the flue gas is sucked back into the glass tube by moving the aspirator flask. The contraction in the volume of the flue gas is noted by reading the level of water in the measuring glass. This gives the amount of carbon dioxide present in the sample of the flue gas.

The procedure is repeated with the other two flasks B and C to find the amount of oxygen and carbon monoxide present in the sample of flue gas.

PERFORMANCE OF I.C ENGINES

1. Testing of I.C engines

An internal combustion (i.c) engine should be tested to check the performance under various operating conditions. These tests are generally classified as:

a) Commercial tests *b) Thermodynamic tests.*

The following are the important reasons for conducting tests in i.c engines.

- To determine the power developed by the engine
- To determine the various efficiencies of the engine
- To determine the fuel consumption
- To ensure the design data
- To detect the sources of heat losses
- To prepare the heat balance sheet

a) Commercial tests: This test is conducted for the following purposes:

- To determine the overload carrying capacity of the engine
- To determine the lubricating oil consumption
- To determine the amount of cooling water required
- To check the valve timings
- To check the stability of the engine at various load condition

b) Thermodynamic tests: This test is conducted for comparing the actual performance of the engine with the theoretical performance.

The following observations are made during this test: Indicated power, brake power, fuel consumption, heat carried away by the exhaust gases, heat carried away by the cooling water, etc. The performance of the engine is determined through various efficiencies and heat balance sheet.

10.2 Indicated power (IP)

Indicated power is the actual power developed inside an engine cylinder. It is measured with the help of indicated mean effective pressure.

Indicator diagram

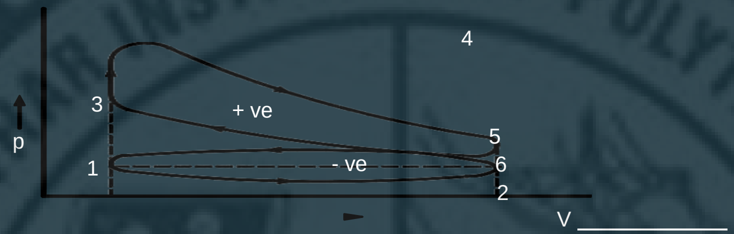


Fig.10.1 Indicator diagram

An indicator diagram is the graphical representation of pressure volume variations during the working cycle. It is drawn by an instrument called indicator. The indicator diagram has a positive loop and a negative loop. The work done during the cycle is given by the area of positive loop. The pumping loss due to suction and exhaust period is given by the area of the negative loop. Therefore the net work done during the cycle is given by,

W= Are of positive loop − Area of negative loop.

$W = (Area\ 3-4-5-6-7-3) - (Area\ 1-2-7-1)$

The area of the indicator diagram is measured by a planimeter or by counting the number of squares in the loops.

Mean height of the indicator diagram is given by,

$$h = \frac{\text{Area of indicator diagram}}{\text{Lenght of indicator diagram}} = \frac{A}{L}$$

Indicated mean effective pressure (p_{mi})

It is the algebraic sum of the mean pressures acting on the piston during each stroke in one complete working cycle. It is measured from the actual indicator diagram.

The indicated mean effective pressure is given by,

p_{mi} = Mean height of indicator diagram × Spring number

$$p_{mi} = h \times S = \frac{A}{L} \times S$$

Number of explosions: It is the number of power strokes or working strokes of an engine in a given time. It is expressed by the symbol ‘*n*’. The number of explosions per second is given by,

$$n = \frac{N}{2}$$ for four stroke cycle engines

$n = N$ for two stroke cycle engines where, N= Engine speed in r.p.s.

The ***indicated power*** of an engine is given by,

$$IP = p_{mi} . l . a . n . k$$

where, p_{mi} = Indicated mean effective pressure

l = Length of stroke of the piston

a = Area of cross–section of piston or cylinder

n = No. of explosions or working strokes per second

k = No. of cylinder.

3. Brake power

Brake power is the useful power available at the crankshaft. This power is less than the actual power (indicated power) developed inside the engine. Dynamometers are used to measure torque. Prony brake dynamometers and rope brake dynamometers are widely used for measuring brake power. Electrical dynamometers and hydraulic dynamometers may also used to determine the brake power.

3. Brake power measurement

Torque is needed for determining the brake power.

a) Prony brake dynamometer : It consists of a brake arm, wooden blocks and weights. The principle of working is the conversion of power into heat by dry friction. The wooden blocks are mounted on a flexible rope or band. The weights are attached to brake arm. Spring loaded blots are provided to loosen or tighten the wooden blocks for varying the friction. A brake is provided to stop the engine.

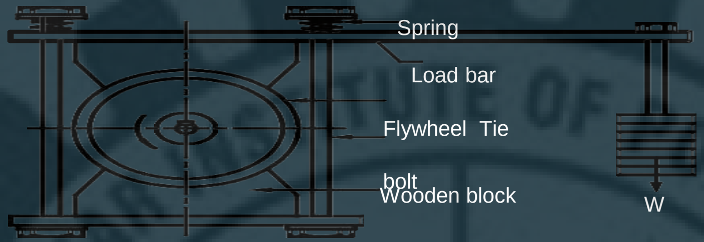


Fig.10.2 Prony brake dynamometer

The wooden blocks are pressed against the rotating drums. The wooden blocks absorb the engine torque and dissipate it as frictional resistance. The entire power is absorbed and converted into heat.

Let, W = Net load on brake (kN)

R = Effective radius of brake drum (m)

N = Speed of the engine (r.p.s)

Torque is given by, $\boldsymbol{T = W.R}$

Brake power is given by, $\boldsymbol{BP = 2.\pi.N.T = \pi.D.N.W}$ (Q $2R = D$)

b) Rope brake dynamometer: It consists of a number of ropes wound around a rotating drum. The drum is driven by the crankshaft of the engine. One end of the rope is connected to a spring balance. The other end is connected to the load. The power is absorbed due to the friction between the rope and the drum.

Let, D_1 = Diameter of the brake drum (m)

d_1 = Diameter of the rope or thickness of the band (m)

W_1 = Weights applied (kN)

W_2 = Spring balance reading (kN)

N = Speed of the engine (r.p.s)

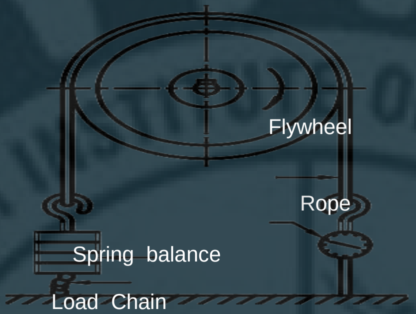


Fig.10.3 Rope brake dynamometer

Effective radius of brake drum, $R = \frac{D_1 + d_1}{2}$

Effective diameter of brake drum, $D = D_1 + d_1$

Net brake load, $W = W_1 - W_2$

Brake torque , $T = W.R$

Brake power, $\boldsymbol{BP = 2.\pi.N.T = \pi.D.\ N.W}$ (Q $2R = D$)

c) Brake power can also be calculated, if brake mean effective pressure is given,

$\boldsymbol{BP = p_{mb}.l.a.n.k}$

where, p_{mb} = Brake mean effective pressure

10.5 Friction power (FP)

Friction power is the power lost mainly due to the friction in the moving parts. It also takes into account the follow losses:

- Mechanical losses in bearings
- Pumping loss due to suction and exhaust
- Air resistance flywheel

Frictional power is the difference between indicated power and brake power.

$\boldsymbol{FP = IP - BP}$

10.6 Efficiencies of engines

a) Indicated thermal efficiency ($\eta_{I.T}$)

It is defined as the ratio of the actual power (indicated power) developed to the heat energy supplied to the engine. It is also called as actual thermal efficiency or thermal efficiency.

$$\text{Indicated thermal efficiency} = \frac{\text{Indicated power}}{\text{Heat supplied}}$$

$$\eta_{I.T} = \frac{IP}{\left(\frac{FC}{3600}\right) \times CV} \times 100 \quad \text{or} \quad \eta_{I.T} = \frac{IP \times 3600}{FC \times CV} \times 100$$

where, IP = Indicated power (kW)

FC = Fuel consumption (kg/hr or m^3 /hr)

CV = Calorific value of the fuel (kJ/kg or kJ/ m^3)

b) Brake thermal efficiency ($\eta_{B.T}$)

It is defined as the ratio of heat converted into useful work (BP) to the heat energy supplied to the engine. Brake thermal efficiency is called as overall efficiency. It varies from 25% to 30%.

$$\text{Brake thermal efficiency} = \frac{\text{Brake power}}{\text{Heat supplied}}$$

$$\eta_{B.T} = \frac{BP}{\left(\frac{FC}{3600}\right) \times CV} \times 100 \quad \text{or} \quad \eta_{B.T} = \frac{BP \times 3600}{FC \times CV} \times 100$$

where, BP = Indicated power (kW)

c) Mechanical efficiency (η_{m})

It is defined as the ratio of brake power to indicated power of an engine. Its value varies from 70% to 90%. It depends upon the loading condition and design of the engine.

$$\text{Mechanical efficiency} = \frac{\text{Brake power}}{\text{Indicated power}}$$

$$\eta_m = \frac{BP}{IP}$$

Mechanical efficiency is also given by,

$$\eta_m = \frac{\text{Brake thermal efficiency}}{\text{Indicated thermal efficiency}} = \frac{\eta_{B.T}}{\eta_{I.T}}$$

$$\text{or, } \eta_m = \frac{\text{Brake mean effective pressure}}{\text{Indicated mean effective pressure}} = \frac{p_{mb}}{p_{mi}}$$

d) Relative efficiency (η_{rel})

It is defined as the ratio of indicated (actual) thermal efficiency to the theoretical (ideal) thermal efficiency. it value varies from 60% to 80%. It is also called as efficiency ratio.

Relative efficiency or efficiency ratio,

$$= \frac{\text{Indicated (actual) thermal efficiency}}{\text{Ideal thermal efficiency (Air standard efficiency)}}$$

$$\eta_{rel} = \frac{\eta_{B.T}}{\eta_{ideal}}$$

e) Volumetric efficiency (η_{vol})

It is defined as the ratio of the actual volume (reduce to N.T.P) of the charge admitted into the engine cylinder during the suction stroke to the stroke volume of the engine.

$$\eta_{vol} = \frac{\text{Volume of the charge admitted during suction}}{\text{Stroke volume of the piston}}$$

$$\eta_{vol} = \frac{V_n}{V_s}$$

The volume reduced to N.T.P is given by, $V_n = \frac{p.V}{p_n} \times \frac{T_n}{T}$

10.7 Specific fuel consumption (*SFC*)

Specific fuel consumption is defined as the amount of fuel consumption to obtain one brake power–hour of work. It is also called as brake specific fuel consumption (*BSFC*)

$$BSFC = \frac{FC}{BP}$$

where, FC = mass of fuel consumed (kg/hr) BP = Brake power (kW)

Brake thermal efficiency is given by,

$$\eta_{B.T} = \frac{BP \times 3600}{FC \times CV} = \frac{3600}{BSFC \times CV} \quad \left[\because BSFC = \frac{FC}{BP}\right]$$

$$\text{or, } BSFC = \frac{3600}{\eta_{B.T} \times CV}$$

Specific fuel consumption may also be given on indicated power basis. It is known as indicated specific fuel consumption (ISFC).

$$ISFC = \frac{FC}{IP} = \frac{3600}{\eta_{I.T} \times CV}$$

10.8 Morse test

Morse test is used to find out the indicated power of a multicylinder i.c. engine. No indicator is used is used in this method.

Procedure for Morse test:

1) The engine is coupled with a brake and the brake power is determined (BP)
2) The first cylinder is now cut–off. This is done by shorting out the spark plug of the first cylinder in the case of petrol engine, and stopping the fuel supply to the first cylinder in the case of diesel engine. The speed of the engine reduces considerably.
3) Load is reduced until the engine attains normal speed.
4) Under this condition, the brake power is determined (BP_1)
5) Then the first cylinder is operated. The second cylinder is cut–off.
6) The engine speed is restored to the normal speed and the brake power is determined (BP_2)
7) The same procedure is repeated for each cylinder in sequence. In each case, the brake power is determined

Let, IP_1, IP_2, IP_3 ,and IP_4 are the indicated power of the cylinders 1, 2, 3, and 4 respectively.

BP = Total brake power of all 4 cylinders

BP_1 = Total brake power of cylinders with cylinder 1 cut–off.

BP_2 = Total brake power of cylinders with cylinder 2 cut–off.

BP_3 = Total brake power of cylinders with cylinder 3 cut–off.

BP_4 = Total brake power of cylinders with cylinder 4 cut–off.

FP_1, FP_2, FP_3 and FP_4 are the frictional power of each cylinder. If all cylinders are working,

$$BP = (IP_1 - FP_1) + (IP_2 - FP_2) + (IP_3 - FP_3) + (IP_4 - FP_4)$$

$$BP = (IP_1 + IP_2 + IP_3 + IP_4) - (FP_1 + FP_2 + FP_3 + FP_4) \quad ..(1)$$

When the first cylinder is cut–off, the IP of the cylinder is cut off. But BP of the cylinder exists. Therefore brake power of the other 3 cylinders is given by,

$$BP_1 = (IP_2 + IP_3 + IP_4) - (FP_1 + FP_2 + FP_3 + FP_4) \quad ..... (2)$$

Subtracting equation(2) from (1), we get

$BP - BP_1 = IP_1$ (Indicated power of first cylinder)

Similarly,

$BP - BP_2 = IP_2$ (Indicated power of second cylinder)

$BP - BP_3 = IP_3$ (Indicated power of third cylinder)

$BP - BP_4 = IP_4$ (Indicated power of fourth cylinder)

The indicated power of the engine is given by,

$$\boldsymbol{IP = IP_1 + IP_2 + IP_3 + IP_4}$$

10.9 Heat balance sheet

Heat energy is supplied in an internal combustion engine by burning the fuel. A part of the heat supplied is converted into useful mechanical work. It is available in the engine crankshaft. The remaining heat energy is lost. The main sources of heat losses are as follows:

1) Heat carried away by the cooling water (Q_w)
2) Heat carried away by exhaust gases (Q_g)
3) Heat lost due to radiation (Q_{rad})

Accounted heat loses : The heat losses which can be determined from the observed values during the test are known as accounted heat losses.

Unaccounted heat losses : The heat losses which cannot be determined accurately are known as unaccounted heat losses. The unaccounted heat losses can be determined by subtracting the accounted heat losses and heat converted into useful work from the heat supplied to the engine.

Procedure for preparing heat balance sheet.

The procedure for preparing the heat balance sheet includes the following:

1) The engine is made to run on constant load at constant speed.
2) The brake power of the engine is estimated.
3) The amount of fuel consumption (FC)is determined.
4) The inlet and outlet temperatures (T_1 and T_2) of the cooling water are noted.
5) The amount of cooling water (m_w) circulate is noted.
6) The temperature of exhaust gas is (T_g) is noted
7) The amount of exhaust gases (m_g) is noted.
8) The room temperature (T_a) is noted.

The heat balance sheet can be prepared on *hour basis, or minute basis or second (kW)* basis.

1) Heat supplied by the fuel (Q_s)

$$Q_s = FC \times CV$$

where, FC = Fuel consumption (kg/hr or m^3 /hr) CV = Calorific value of fuel (kJ/kg.K)

2) Heat equivalent of useful work (Brake power) (Q_{BP}):

$$Q_{BP} = BP \times 3600$$

Percentage of heat used for brake power,

$$Q_{BP}\ \% = \frac{Q_{BP}}{Q_s} \times 100$$

3) Heat lost due to cooling water:

$$Q_w = m_w . C_{pw} . (T_2 - T_1)$$

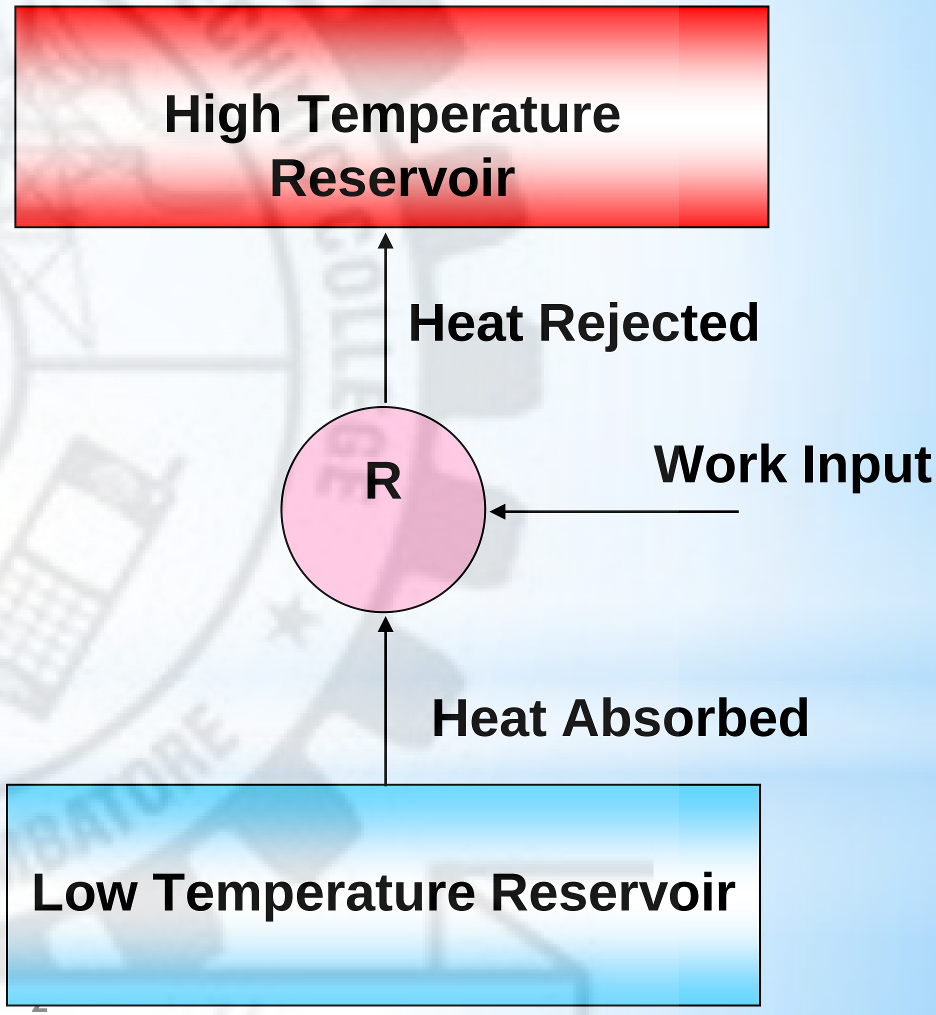
Refrigeration & Air Conditioning

- **Introduction**
- **Type of refrigeration**
- **Types Of Air Conditioner**

Introduction

How does it work?

Refrigeration and air conditioning is used to cool products or a building environment.



Introduction

Refrigeration systems for industrial processes

- **Small capacity modular units of direct expansion type** (50 Tons of Refrigeration)
- **Centralized chilled water plants with chilled water as a secondary coolant** (50 – 250 TR)
- **Brine plants with brines as lower temperature, secondary coolant** (>250 TR)

Types of Refrigeration

Refrigeration systems

- Vapour Compression Refrigeration (VCR): uses mechanical energy
- Vapour Absorption Refrigeration (VAR): uses thermal energy
- Magnetic Refrigeration: remove heat and maintain low temperature
- Industrial Refrigeration:used in cold storage

Type of Refrigeration

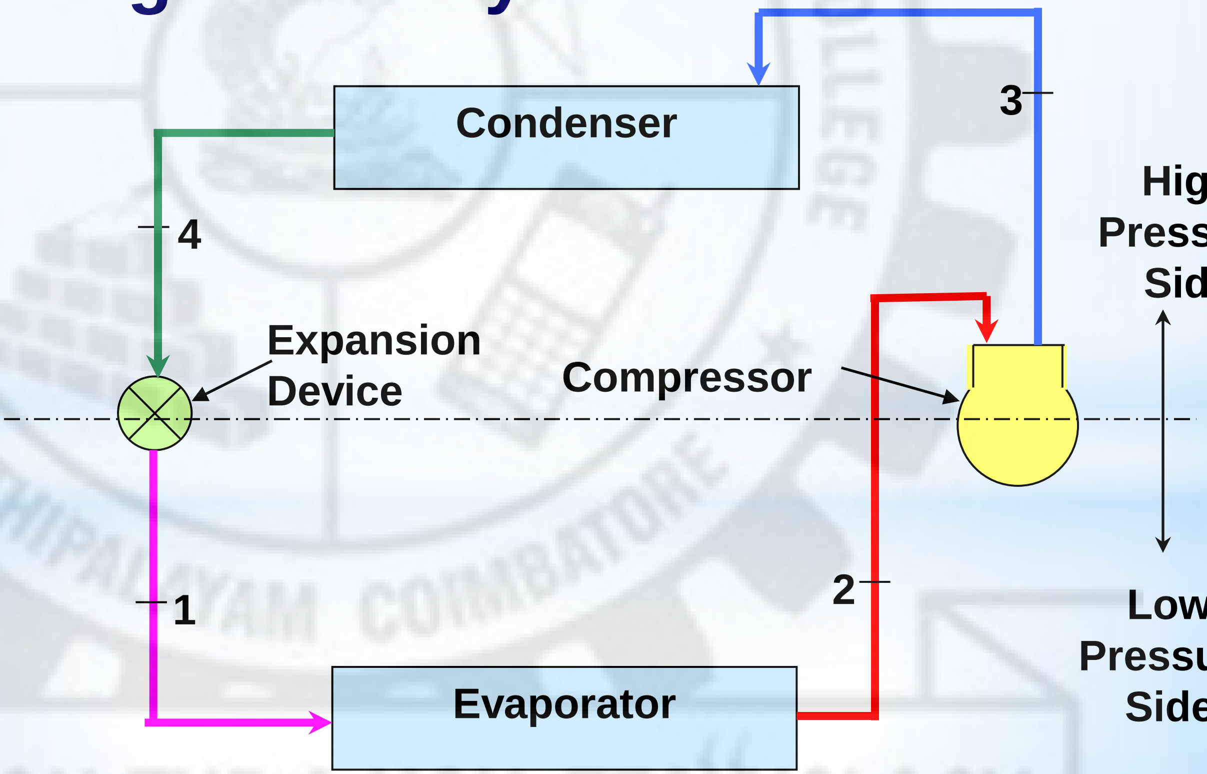
Vapour Compression Refrigeration

- Highly compressed fluids tend to get colder when allowed to expand
- If pressure high enough
  - Compressed air hotter than source of cooling
  - Expanded gas cooler than desired cold temperature

Type of Refrigeration

Vapour Compression Refrigeration

Refrigeration cycle



Type of Refrigeration

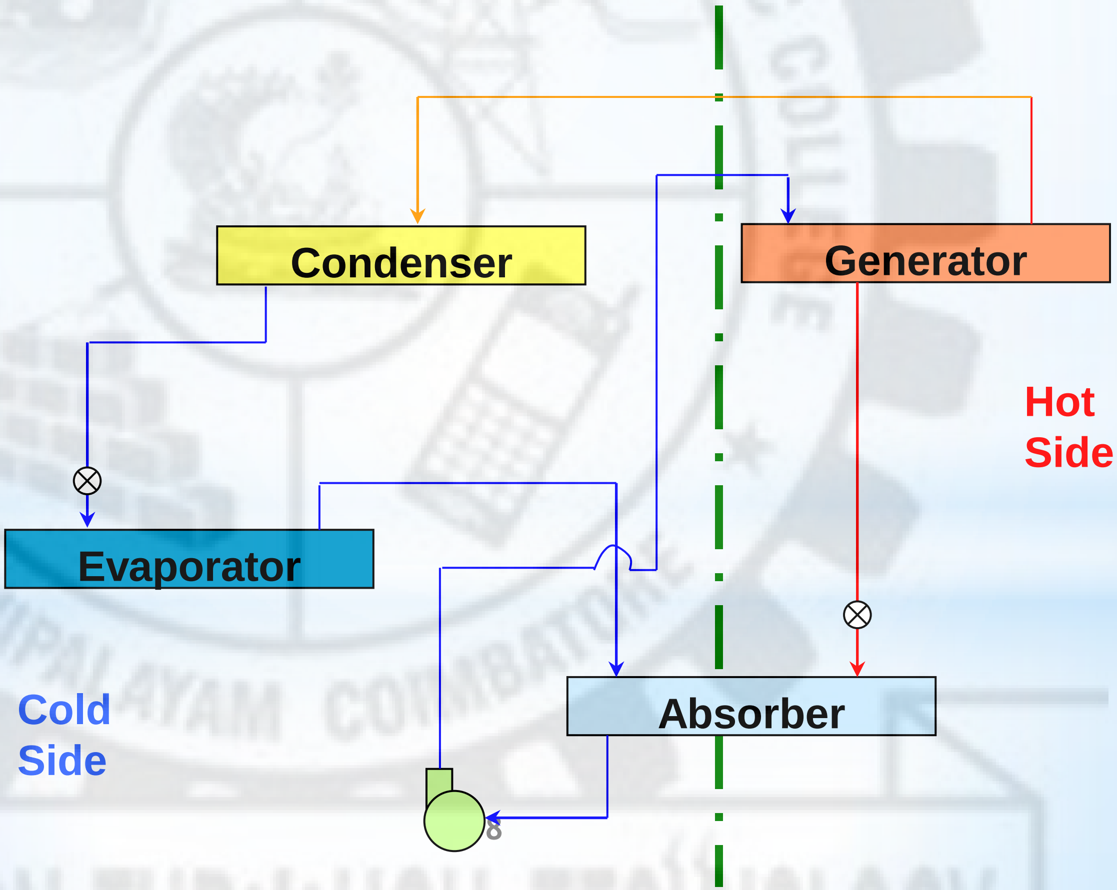
Vapour Absorption Refrigeration

- The absorption system differs fundamentally from vapour compression system only in the method of employed for compressing the refrigerant.
- In the absorption system, the compressor is replaced by an absorber, generator and a pump.

Refrigeration & AC

Type of Refrigeration

Vapour Absorption Refrigeration



Type of Refrigeration

Magnetic Refrigeration

- Magnetic refrigeration is a cooling technology based on the magneto caloric effect.

- It is used to attain temperature well below 1 Kelvin

Type of Refrigeration

Industrial Refrigeration

- Industrial refrigeration systems for cold storage, process cooling, water chilling, individual quick freezing .

- Up to 500 TR capacity using halocarbon or ammonia.

- Complete with compressors, condensers, all vessels and electrical equipment required

Air Conditioning System

- An air conditioning system is an assembly of different part of the system used produce a specified condition of air within a require space or building.
- The basic elements of air conditioning system:--
- Fans : For circulation of air
- Filters : For cleaning air
- Heating Elements : Heating of air(It may be electric heater , steam , hot water.
- Control System : It regulates automatically the amount of cooling or heating.
- Grill : It adjust the direction of the conditioned air to the room.
- Tray : It collects condensed water.
- Refrigerating Plant : provide cooling . It consist of compressor/generator and absorber,eveporator,condensor,expansion device(capallary tube).

Types Of Air Conditioning Sysytem

Refrigeration & AC

Air Conditioning System

- Window air-conditioning system
- Split air-conditioning system
- Centralised air-conditioning system
- Package air-conditioning system

- Window air conditioners are one of the most commonly used and cheapest type of air conditioners

- To install one of these units, you need the space to make a slot in the wall, and there should also be some open space behind the wall.

Window air-conditioning system

Split Air-Conditioning System

- The split air conditioner comprises of two parts: the outdoor unit and the indoor unit

- The *outdoor unit*, fitted outside the room, houses components like the compressor, condenser and expansion valve.

Centralised Air-Conditioning System

- The central air conditioning plants or the systems are used when large buildings, hotels, theaters, airports, shopping malls etc. are to be air conditioned completely.

- The window and split air conditioners are used for single rooms or small office spaces

Packaged Air-Conditioning System

- The packaged air conditioners are used for the cooling capacities in between these two extremes.

- The packaged air conditioners are available in the fixed rated capacities of 3,5, 7, 10 and 15 tons.

- These units are used commonly in places like restaurants, telephone exchanges, homes, small halls, etc

Compressor

Condenser

Evaporator

Receiver

Window Air Conditioning **Split Air Conditioning**

Packaged Air Conditioning Centralised Air Conditioning

Unit I

1.Determine the final temperature, external work done ,change in internal energy ,change in enthalpy and change in entropy in the case of 2Kg of gas at 50^{O}cbeing heated at constant volume until the pressure is doubled.

2.A quantity of air occupies a volume of 30 litres at temperature of 38^{O} c and a pressure of $104kN/m^2$.The temperature of air can be raised by heating at constant volume until the pressure is $208kN/m^2$.Find the final temperature, external work done ,change in internal energy and heat transferred. Take c_v=0.72 kj/kg.k R=0.287 kj/kg.k

3.0.35m^3 of air at 22^{o}c and under atmospheric pressure is heated under constant volume to a temperature of 100oc.Assume c_p=1 KjKg k and c_v=0.71 kj/Kg k.Find mass of air, final pressure , heat transferred, work done ,change in internal energy.

4.A mass of gas has a pressure of 10 bar and a volume of 24litres at a temperature of 23^{o}c.Find the mass of gas if the pressure of the gas drops to 5 bar isothermally.Find also the workdone and heat transferred.Assume R=0.292 kj/kg.k

Unit II

5.In a ideal constant volume cycle, the pressure and temperature at the beginning of compression are $97KN/m^2$ and 50 ^{o}c respectively.The ratio of compression is 5:1.the heat supplied during the cycle is 930 kJ/Kg of working fluid.Determine a)the maximum temperature attained in the cycle b)the thermal efficiency of the cycle and c)the workdone during cycle/kg of the working fluid.Assume $^{\gamma}$=1.4 c_v=0.717 kj/kg. k

6.an engine working on the ideal constant volume cycle has a piston of 100mm diameter and 100mm stroke.The clearance volume is 0.105 litres.If its relative efficiency is 40%.Calculate the actual thermal efficiency.Take $^{\gamma}$=1.4

7.An air standard diesel cycle has a compression ratio of 18 and the heat transferred to the working fluid per cycle is 1800 Kj/Kg.At the beginning of the compression stroke the pressure is 1 bar and the temperature is 300 Calculate temperature at each point in the cycle.C_p=1.005KjKg k,C_v=0.718 Kj/Kg k,R=0.287 Kj/kg k

8.What will be the loss in ideal efficiency of a diesel cycle engine with compression ratio 14,if the fuel cutoff is delayed from 6% to 9% of the stroke. $^{\gamma}$=1.4

Unit III

9.Straight valve (straight poppet valve) mechanism

10.overhead valve mechanism

11. two stroke petrol engine

12.four stroke petrol engine

13. two stroke diesel engine

14.four stroke diesel engine

15.A.c mechanical fuel pump

16.Simple carburetor

17.battery coil ignition system

18.Magneto ignition system

19.Multi point fuel injection system(MPFI)

20.common rail direct injection (CRDI)

Unit IV

21.Exhaust gas analyzer

22.orsat apparatus

23.Bomb calorimeter

24. Junker gas calorimeter

25.During a test on 4 stroke oil engine the following data were obtained.
Swept volume of the cylinder=14 litres
Speed of the engine=6.6 rps
Effective brake radius =0.7 m
Indicated mean effective pressure=567 KN/m^2
Calculate the indicated power, brake power and the mechanical efficiency.

26. A six cylinder four stroke engine has a bore to stroke ratio of 360:500 mm. During the trail, following results were obtained
Mean area of indicator diagram=0.00075m^2:length of indicator diagram 0.075m, spring number-70,000 KN/m^2 per m of compression: brake torque 14 KNm speed 500 r.p.m.Fuel consumption 240 kg/hr.
Calculate i)Total indicated power developed,ii)brake power iii)Mechanical efficiency iv)specific fuel consumption

Unit V

27.vapour compression refrigeration
28.Vapour absorbtion refrigeration
29.pyschromatic process
30.window air conditioner
31.central air conditioner
32.facotrs to be considered in air conditioning
33.Load encountered in air conditioning systems