IC Engine

Engine:

An engine is a device which transforms one form of energy into another form with consideration of efficiency.

Heat engine:

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy & utilizes this thermal energy to perform useful work.

Thus; thermal energy is converted into mechanical energy

Heat engines are broadly classified into following catagories:

(I) Internal combustion Engines (IC Engine)

(II) External combustion Engines (EC Engine)

classification:

HEAT ENGINES

- IC Engine
  - Rotary
    - open cycle Gas Turbine.
    - Wankel Engine
  - Reciprocating
    - Petrol engine
    - Diesel engine
- EC Engines
  - Reciprocating
    - steam engine
    - stirling engine
  - Rotory
    - steam turbine
    - Closed cycle Gas turbine

IC Engine:

It is the Engine where combustion takes place inside or within a engine.

e.g. Petrol engine, Diesel engine.

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External combustion Engine:

In this, combustion takes place outside the engine.

eg. steam engine, steam turbine etc.

Classification of IC engine

IC Engine

- According to types of strokes
  - Four Stroke
  - Two Stroke
- According to cycle of operation
  - SI Engine (Otto cycle)
  - CI engine (Diesel cycle)
- According to Fuel used
  - SI Engine (Otto cycle):
    - Petrol Engine
    - Gas Engine
  - CI engine (Diesel cycle):
    - Diesel Engine
    - Bi-Fuel or multifuel engine
- According to type of cooling
  - Air cooled
  - Water cooled
- According to type of motion
  - Rotary Engine
  - Reciprocating Engine
- According to Number of cylinders
  - Reciprocating Engine:
    - Single cylinder
    - multicylinder engine

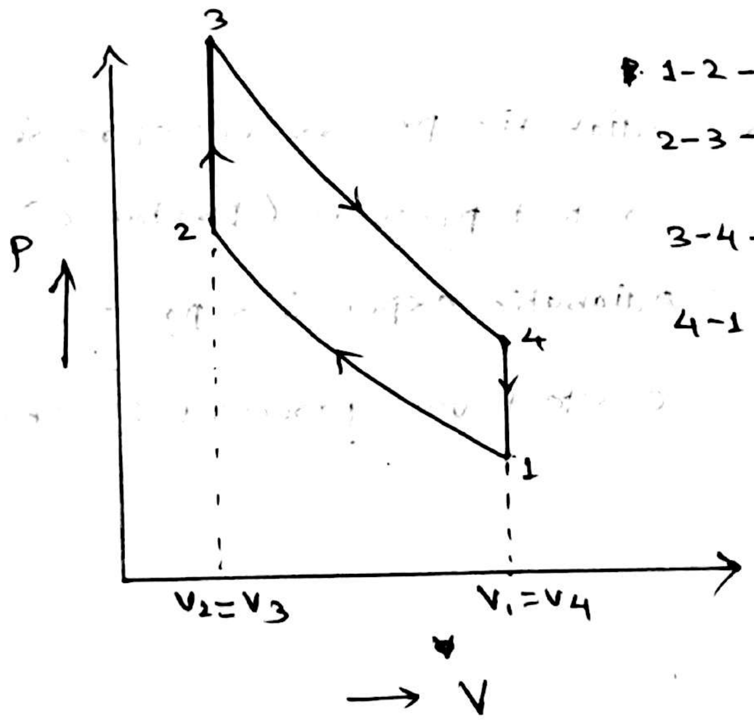
A/P: Vijay Bhendwade

For successful working of an engine; it has to follow a cycle of operation in sequential manner.

- working of spark Ignition Engine (SI) & compression ignition Engine (CI), follows, Otto cycle and Diesel cycle respectively.

- The credit of inventing the spark-ignition engine goes to Nicolaus A. Otto (1876) whereas compression ignition engine was invented by Rudolf Diesel (1892) hence they are reffered as Otto cycle & Diesel cycle respectively.

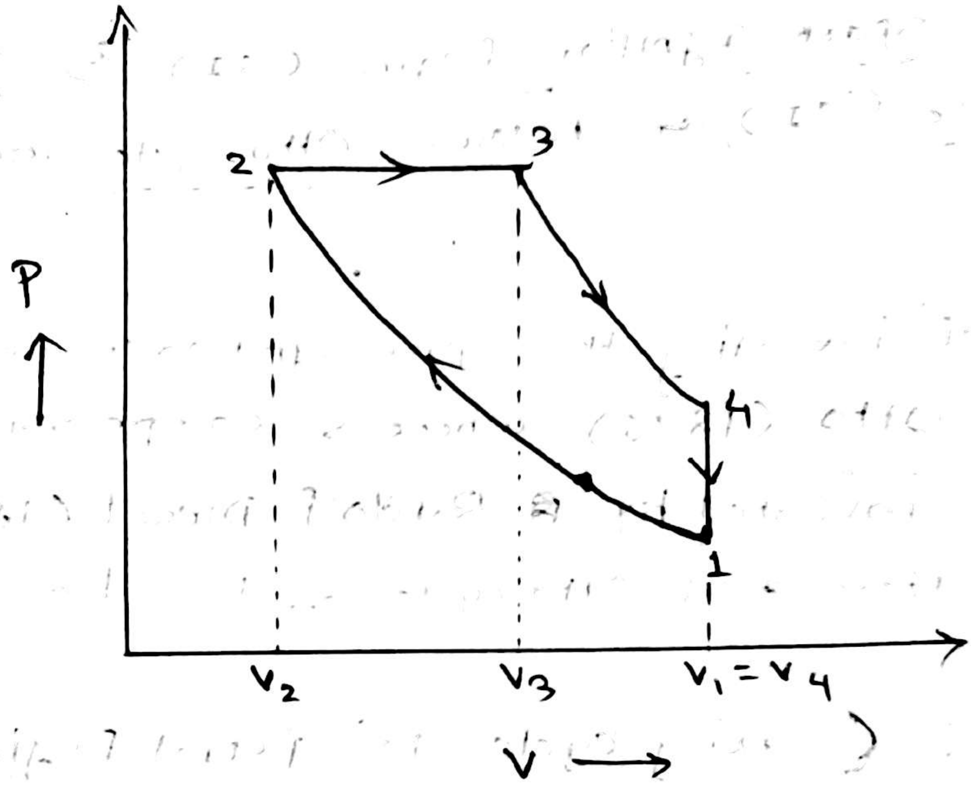
★ Otto Cycle: (working cycle for Petrol Engine)



- 1-2 → Adiabatic process
- 2-3 → constant vol^m Heat addition (compression)
- 3-4 → Adiabatic expansion
- 4-1 → constant vol^m process (expansion)

Fig. shows P-V diagram of Otto cycle consists of two adiabatic processes & two constant vol^m processes.

* Diesel cycle: (working cycle of Diesel engine)



<u>Process</u>

1-2 → Adiabatic process (compression)

2-3 → Constant pressure (Isobaric) process

3-4 → Adiabatic expansion process

4-1 → Constant volm process (Isochoric)

1.2.1 Engine Components

A cross section of a single cylinder spark-ignition engine with overhead valves is shown in Fig.1.2. The major components of the engine and their functions are briefly described below.

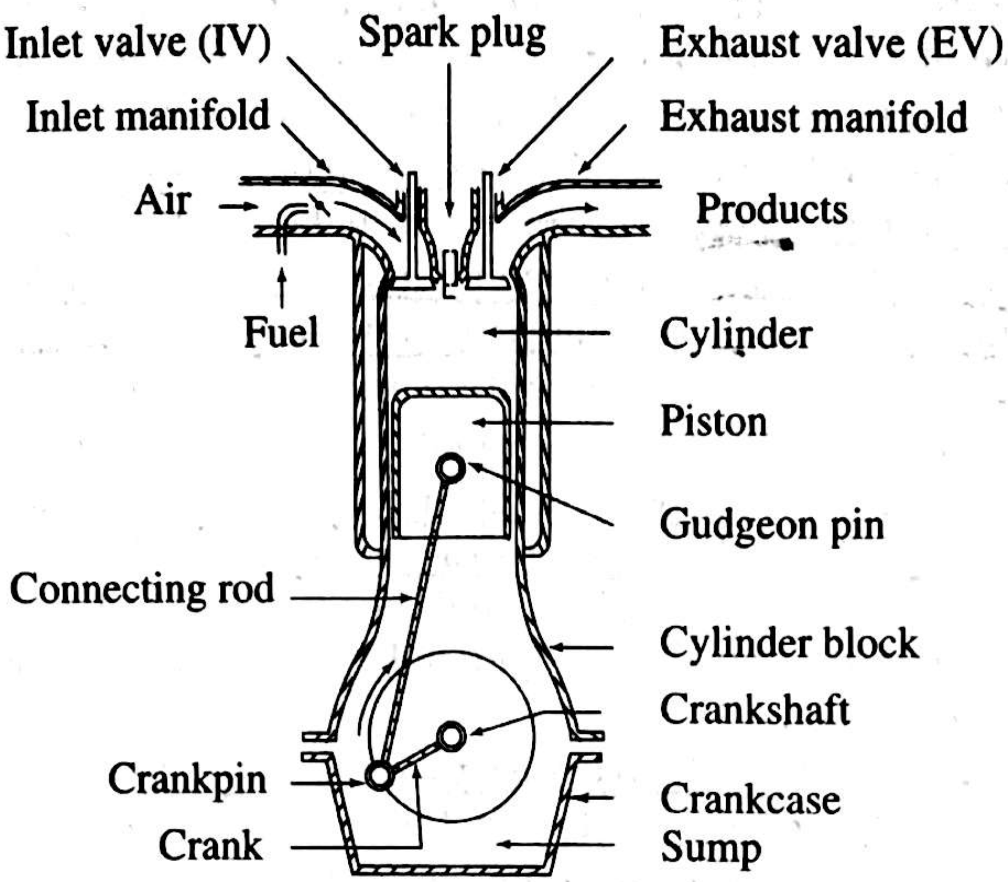


Fig. 1.2 Cross-section of a spark-ignition engine

I) **Cylinder Block :** The cylinder block is the main supporting structure for the various components. The cylinder of a multicylinder engine are cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling. Cylinder head gasket is incorporated between the cylinder block and cylinder head. The cylinder head is held tight to the cylinder block by number of bolts or studs. The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the crankcase. The inner surface of the cylinder block which is machined and finished accurately to cylindrical shape is called bore or face.

II) **Cylinder :** As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and

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subjected to different thermodynamic processes. The cylinder is supported in the cylinder block.

III) **Piston :** It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly (snugly) into the cylinder providing a gas-tight space with the piston rings and the lubricant. It forms the first link in transmitting the gas forces to the output shaft.

(IV) **Combustion Chamber :** The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

Inlet Manifold : The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.

Exhaust Manifold : The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

V) **Inlet and Exhaust Valves :** Valves are commonly mushroom shaped poppet type. They are provided ~~either on the cylinder head or on the side of the cylinder~~ for regulating the charge coming into the cylinder (inlet valve) and for discharging the products of combustion (exhaust valve) from the cylinder.

VI) **Spark Plug :** It is a component to initiate the combustion process in Spark-Ignition (SI) engines and is usually located on the cylinder head.

VII) **Connecting Rod :** It interconnects the piston and the crankshaft and transmits the gas forces from the piston to the crankshaft. The two ends of the connecting rod are called as small end and the big end (Fig.1.3). Small end is connected to the piston by gudgeon pin and the big end is connected to the crankshaft by crankpin.

VIII) **Crankshaft :** It converts the reciprocating motion of the piston into useful rotary motion of the output shaft. In the crankshaft of a single cylinder engine there are a pair of crank arms and balance weights. The balance weights are provided for static and dynamic balancing of the rotating system. The crankshaft is enclosed in a crankcase.

(IX) **Piston Rings :** Piston rings, fitted into the slots around the piston, provide a tight seal between the piston and the cylinder wall thus preventing leakage of combustion gases (refer Fig.1.3).

(X) **Gudgeon Pin :** It links the small end of the connecting rod and the piston.

Camshaft : The camshaft (not shown in the figure) and its associated parts control the opening and closing of the two valves. The associated parts are push rods, rocker arms, valve springs and tappets. This shaft also provides the drive to the ignition system. The camshaft is driven by the crankshaft through timing gears.

Cams : These are made as integral parts of the camshaft and are so designed to open the valves at the correct timing and to keep them open for the necessary duration (not shown in the figure).

(XI) **Fly Wheel :** ~~The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change~~ in the angular

It is heavy wheel mounted on crankshaft.
It minimizes fluctuations of speed.

Engine Nomenclature

(I) cylinder bore (d):

It is nominal inner diameter of working cylinder is called cylinder bore

(II) piston Area: (A)

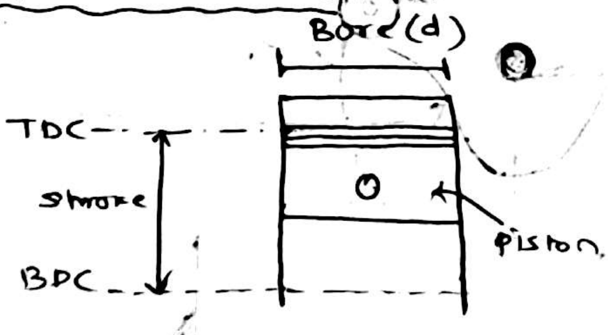
It is area of circle of diameter equals to cylinder ~~bore~~ bore (d)

(III) Stroke: (L)

It is nominal distance through which working piston moves from top dead centre to bottom dead centre.

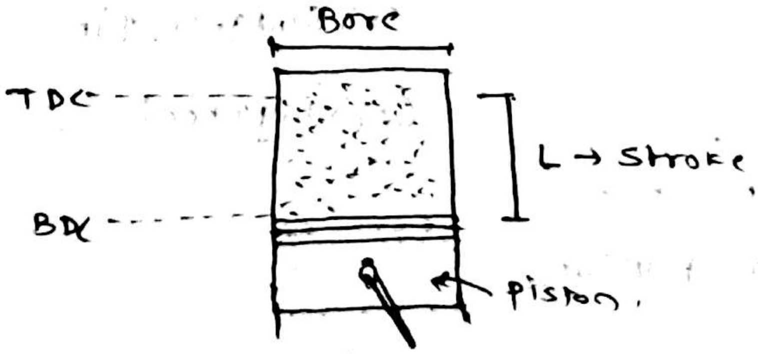
(IV) Dead centres:

(i) Top dead centre:



It is the ~~dea~~ position of piston ~~at~~ near to cylinder head at extreme.

(ii) Bottom dead centre:



It is the position of Piston away from cylinder head at extreme position.

(V) Swept vol^m or Displacement vol^m : (V_s)

It is nominal vol^m swept by working piston when travelling from one dead centre to another dead centre.

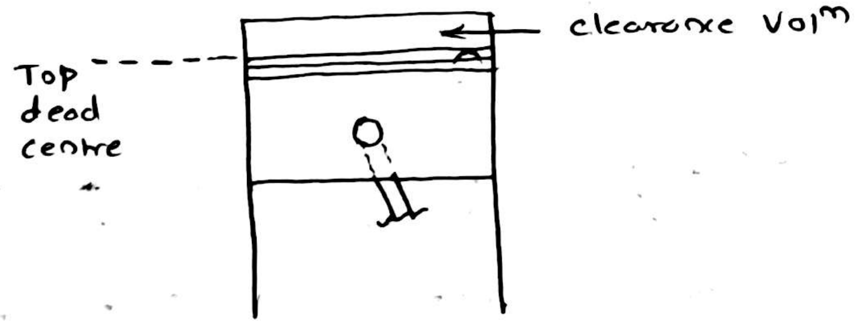
It is expressed by cubic centimeter (cc) of engine.

$$V_s = \left(\frac{\pi}{4} \times d^2\right) \times (\text{stroke})$$

$$= (\text{piston Area}) \times (\text{stroke})$$

$$\boxed{V_s = A \times L}$$

(VI) Clearance vol^m : (V_c)



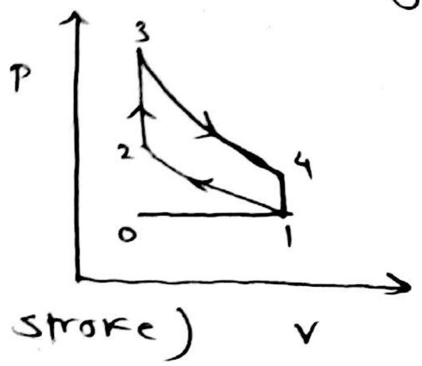
It is nominal vol^m of combustion chamber above the piston; when it is at top dead centre, is called clearance vol^m. (V_c)

Working of 4-Stroke Spark Ignition Engine (Petrol Engine)

(4-stroke SI engine)

→ (i) In four-stroke engine, the cycle of operation is completed in four strokes of piston or two revolution of crankshaft.

(ii) Ideal four stroke SI engine consists of following four strokes :

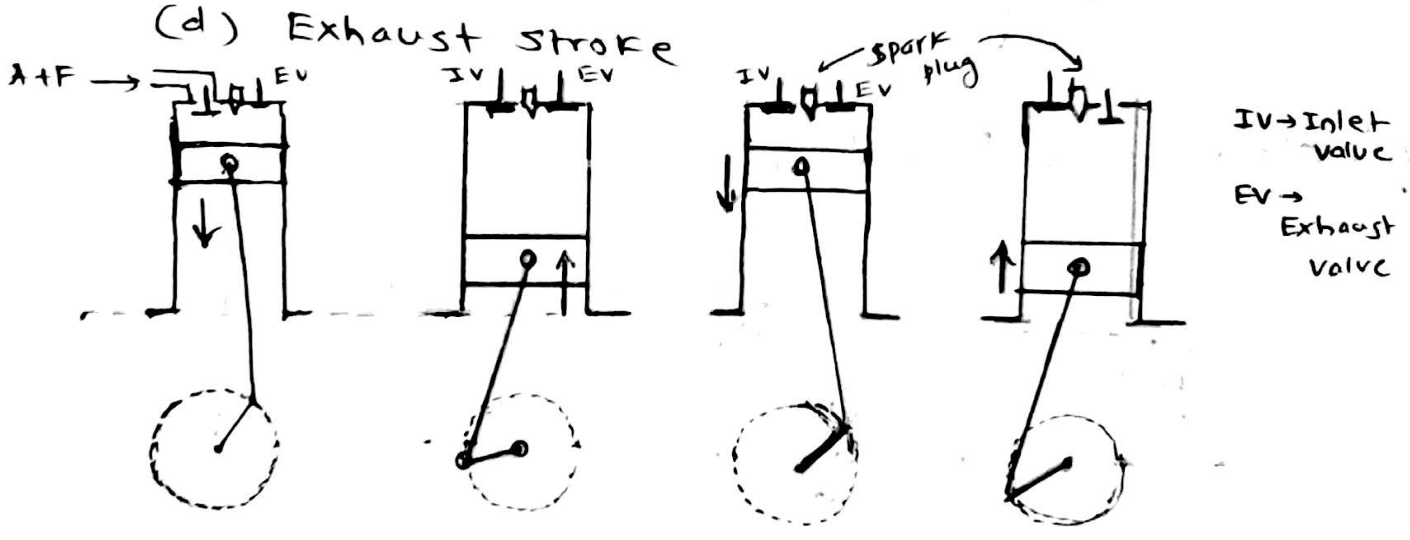


(a) suction or Intake stroke

(b) compression stroke

(c) Expansion stroke (power stroke)

(d) Exhaust stroke



suction   compression   Expansion   Exhaust

(a) suction stroke : (0-1)

→ It starts when piston is at top dead centre & about to move downwards.

→ Inlet valve is open & exhaust valve is at closed position.

→ This creates the suction due to which Air + Fuel mixture is drawn into cylinder.

→ when piston reaches bottom dead centre, inlet valve closes.

(b) compression stroke : (1-2)

(i) whatever charge (Air+Fuel) taken into cylinder in suction stroke is compressed by upward movement of piston

(ii) During this stroke, both valves ~~etc~~ are in closed position.

(iii) At the end of compression stroke; the mixture is ignited with the help of spark plug located ~~at~~ on the ~~the~~ cylinder head. & burning of charge takes place at constant volm

(iv) Due to burning process, chemical energy is converted into heat energy; producing temperature of about $2000°c$. (2-3)

(v) The pressure at the end of combustion process is considerably increased due to heat release from fuel. (2-3)

(c) Power stroke or Expansion stroke : (3-4)

(i) The high pressure of burnt gases forces the piston in downward direction

(ii) Both the valves are closed position

(iii) Both pressure & temperature decreases during expansion.

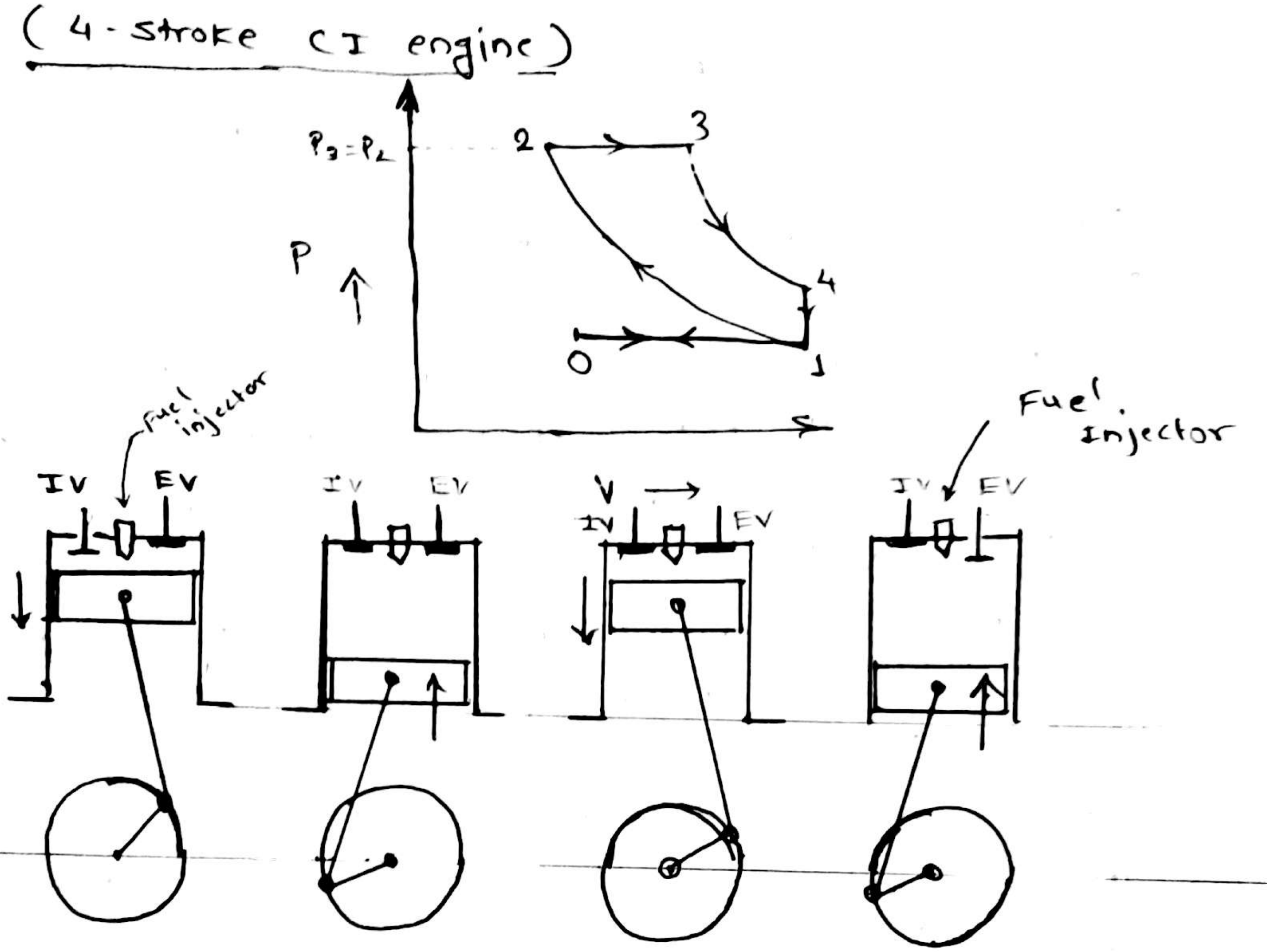
(iv) this is the only stroke; where power is produced.

(d) Exhaust stroke :

(i) At the end of expansion stroke; exhaust valve open & inlet valve remain closed.

(ii) piston moves towards Top dead centre or in upword which sweeps burnt gases out.

Working of 4-Stroke Compression Ignition Engine (Diesel Engine)



→ four stroke CI engine is similar to four stroke SI engine; but it operates at higher compression ratio

→ The carburettor & ignition system is necessary in the SI engine; not required in CI engine.

a) suction stroke:

→(i) Inlet valve is open & exhaust valve is closed

(ii) only air is inducted during the suction stroke

b) compression stroke:

(i) whatever air inducted during suction stroke; compressed in this stroke due to upward motion of piston.

(ii) Both the valve remains closed

(c) Expansion stroke:

(i) Fuel injection starts nearly at end of compression stroke

(ii) Due to increased pressure & temperature combustion starts at the point where temperature reaches self-ignition temperature of fuel.

(iii) After injection of fuel is completed; the product of combustion expands & piston moves downword.

(iv) Both valve remained closed in this stroke

(d) Exhaust stroke:

(i) piston travelling from Bottom to top, which pushes the product of combustion.

(ii) Exhaust valve open & intake valve closed

Table 1.1 Comparison of SI and CI Engines

Description	SI Engine	CI Engine
Basic cycle	Works on Otto cycle or constant volume heat addition cycle.	Works on Diesel cycle or constant pressure heat addition cycle.
Fuel	Gasoline, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low.
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburettor and an ignition system are necessary. Modern engines have gasoline injection.	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.
Load control	Throttle controls the quantity of fuel-air mixture to control the load.	The quantity of fuel is regulated to control the load. Air quantity is not controlled.
Ignition	Requires an ignition system with spark plug in the combustion chamber. Primary voltage is provided by either a battery or a magneto.	Self-ignition occurs due to high temperature of air because of the high compression. Ignition system and spark plug are not necessary.
Compression ratio	6 to 10. Upper limit is fixed by antiknock quality of the fuel.	16 to 20. Upper limit is limited by weight increase of the engine.
Speed	Due to light weight and also due to homogeneous combustion, they are high speed engines.	Due to heavy weight and also due to heterogeneous combustion, they are low speed engines.
Thermal efficiency	Because of the lower CR, the maximum value of thermal efficiency that can be obtained is lower.	Because of higher CR, the maximum value of thermal efficiency that can be obtained is higher.
Weight	Lighter due to comparatively lower peak pressures.	Heavier due to comparatively higher peak pressures.

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★ TWO STROKE ENGINE :

→ Two stroke engine is an alternative arrangement for suction & exhaust stroke. In 4-stroke engine there are two unproductive strokes of exhaust & suction for flushing out products of combustion & filling a fresh charge inside the cylinder respectively.

→ Dugald clark (1878) invented two stroke engine.

⇒ Figure shows, crankcase scavenged two stroke SI engine;

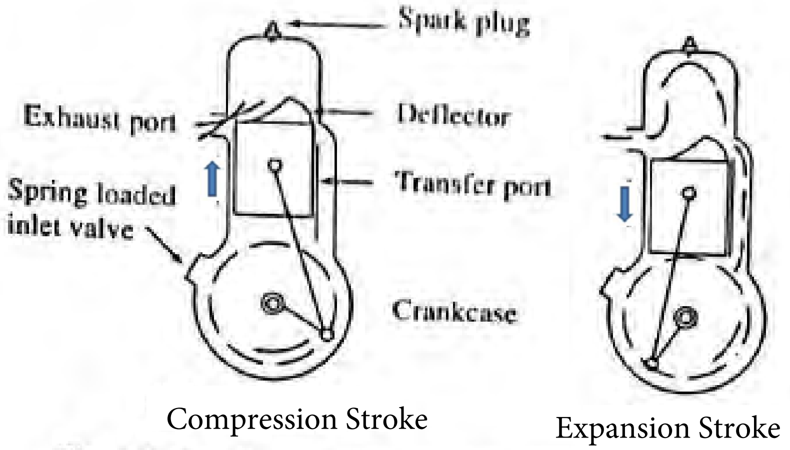

Fig. 1.8 Crankcase scavenged two-stroke SI engine

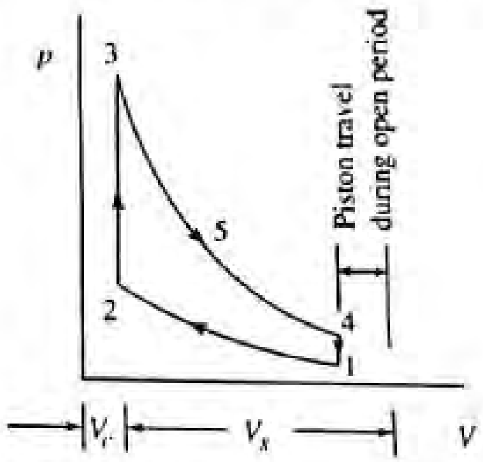

Fig. 1.9 Ideal p-V diagram of a two-stroke SI engine

(I) Compression stroke:

(i) The ~~at~~ air- fuel charge is inducted into crankcase through spring loaded inlet valve.

(ii) piston moves upword & pressure in crank-case reduced

(iii) After compression ~~at~~(nearly at the end of compression) ignition takes place.

(II) Expansion stroke.

(i) During expansion stroke; charge in crankcase get compressed.

(ii) Near ~~end~~ the end of the expansion stroke, piston uncovers the exhaust ports & cylinder pressure drops ~~to~~ & by means of scavenging combustion products leaves the cylinder

Scavenging

In two stroke engine, the piston top usually have a projection to deflect fresh charge towards top of cylinder preventing the flow through the exhaust port (for fresh charge) and pushes combustion product through exhaust port.

This double purpose arrangement in two stroke engine is called scavenging.

INDICATED POWER (I.P.)

The power produced inside the engine cylinder by burning of fuel is known as Indicated power (I.P.) of engine.

we know that,

$$\text{power} = \frac{\text{Work}}{\text{time}} \quad \text{i.e. rate of doing work}$$

& work = Force × displacement

$$= \cancel{\left[\frac{\text{Pressure}}{\text{Area}}\right] \times \text{Area} \times \text{disp}}$$

$$= \left[\frac{\text{Force}}{\text{Area}}\right] \times \text{Area} \times \text{displacement}$$

$$\text{work} = \text{pressure} \times \text{Area} \times \text{displacement}$$

Note: here pressure is considered as average pressure or mean effective pressure (P_m)

$$\textbf{Power} = \frac{\text{work}}{\text{time}}$$

$$= (\text{work}) \times \left[\frac{1}{\text{time}}\right]$$ For 1 Power stroke ~~revolution~~ ~~of~~ per min.

~~5 work~~ ×

∴ for ~~N~~ ~~revolution~~ power stroke per min.

$$\text{power} = \text{work} \times \cancel{N}(n)$$ ∵ ~~N → r.p.m~~ ~~i.e per time~~

∴ ~~$Power = P_m \times A \times L \times N$~~

$$\therefore \boxed{\text{Power} = P_m \times A \times L \times n}$$

For 4-Stroke : $n = \frac{N}{2}$ ∵ N = R.P.M of engine

For 2-Stroke : $n = N$

$$\text{Indicated power} = P_m \times A \times L \times \left(\frac{N}{2}\right)$$ ~~Joule min~~ J/m

$$= \frac{P_m \times A \times L \times N}{60 \times 2} \text{ Joule/sec.}$$

$$\boxed{I.P = \frac{P_m \times A \times L \times N}{60 \times 2}}$$ Watt. For 4-Stroke

- $L \rightarrow$ Stroke length or piston displacement
- $A \rightarrow$ Area of piston
- $P_m \rightarrow$ mean effective pressure
- $n \rightarrow$ No. of power strokes per min
- $N \rightarrow$ rpm of engine

$$\boxed{IP = \frac{P_m \times A \times L \times N}{60}}$$ Watt For 2-Stroke

BRAKE POWER : (B.P.) (Engine o/p power)

It is power available at engine crank shaft for doing useful work. It is measured by dynamometer.

$$B.P. = \frac{P_{mb} \times L \times A \times n}{60} \text{ Watt}$$

$\because$ $n = \frac{N}{2}$ → for 4-stroke

$n = N$ → for 2-stroke

$\because$ P_{mb} → Brake mean effective pressure

Various Dynomometers are used to measure Brake Power:

(a) Rope brake dynamometer

(b) Hydraulic dynamometer

(c) Prony brake dynomometer

(d) Eddy current dynomometer.

$$= \frac{2\pi NT}{60}$$

(**<u>This is another formula to calculate brake power But here consider directly 'N' for 4-Stroke as well as 2 stroke</u>**)

T= Torque in *N-m*

AIR STANDARD EFFICIENCY :

$$\eta_{air}\Big|_{Petrol} = 1 - \frac{1}{(r_c)^{\gamma-1}}$$

$$\eta_{air}\Big|_{Diesel} = 1 - \frac{1}{(r_c)^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$$

$\because$ $\gamma = \frac{C_p}{C_v}$

r_c = compression ratio

ρ = cut-off ratio ~~or pressure~~

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★ SPECIFIC OUTPUT :

$$Sp.\ O/P = \frac{\text{Brake Power}}{\text{Piston Area}}$$

$$= \frac{B \cdot P}{A}$$

★ SPECIFIC FUEL CONSUMPTION :

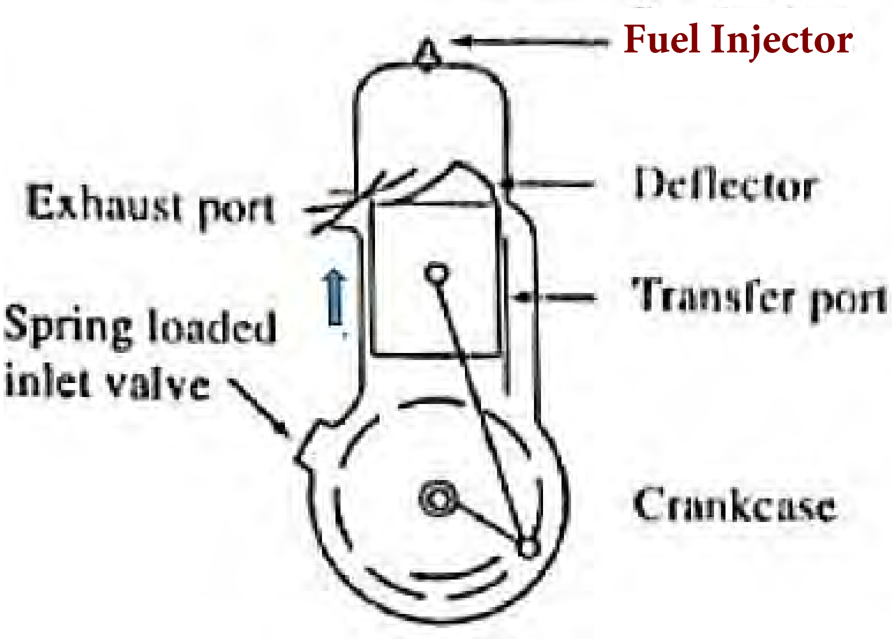
It is amount of fuel consumed by an engine for unit power production

$$SFC = \frac{m_f}{B \cdot P} \quad kg/kWh$$

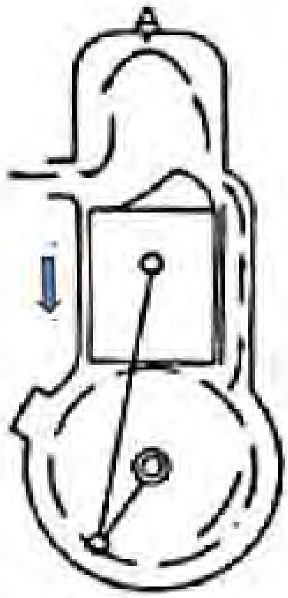
$\because$ m_f = mass of fuel in Kg.

$B \cdot P$ = Brake Power

Working of 2-Stroke Compression Ignition Engine(Diesel Engine)



Compression Stroke



Expansion Stroke

The main difference between 2 Stroke SI & CI engine is the replacement of spark plug by Fuel injector in CI engine.

<u>FIRST STROKE:</u> (Compression Stroke)

i) Only air is inducted into crankcase through spring loaded inlet valve
ii) Piston moves upward so that pressure in crankcase reducing and in cylinder (i.e above piston) increasing.
iii) Also temperature in cylinder increases tremendeously.
iv) Nearly at the end of compression stroke fuel injector in cylinder head injects the fuel into cylinder and due to high pressure and temperature combustion starts. (for previously taken air from transfer port and fuel which is injected in this stroke combustion takes place)

<u>SECOND STROKE:</u> (Expansion Stroke)

i) This is the power stroke.
ii) In this stroke piston moves down to compress air in the crankcase so that, from transfer port air moves to the cylinder (i.e above piston)
iii) By means of scavenging action burnt gases are exausted via exhaust port.

Table 1.2 Comparison of Four and Two-Stroke Cycle Engines

Four-Stroke Engine	Two-Stroke Engine
(i) The thermodynamic cycle is completed in four strokes of the piston or in two revolutions of the crankshaft. Thus, one power stroke is obtained in every two revolutions of the crankshaft.	(i) The thermodynamic cycle is completed in two strokes of the piston or in one revolution of the crankshaft. Thus there is one power stroke for every revolution of the crankshaft.
Because of the above, turning moment is not so uniform and hence a heavier flywheel is needed.	Because of the above, turning moment is more uniform and hence a lighter flywheel can be used.
(ii) Again, because of one power stroke for two revolutions, power produced for same size of engine is less, or for the same power the engine is heavier and bulkier.	ii) Because of one power stroke for every revolution, power produced for same size of engine is twice, or for the same power the engine is lighter and more compact.
(iii) Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lower rate of wear and tear.	iii) Because of one power stroke in one revolution greater cooling and lubrication requirements. Higher rate of wear and tear.
(iv) Four-stroke engines have valves and valve actuating mechanisms for opening and closing of the intake and exhaust valves.	iv) Two-stroke engines have no valves but only ports (some two-stroke engines are fitted with conventional exhaust valve or reed valve).
(v) Because of comparatively higher weight and complicated valve mechanism, the initial cost of the engine is more.	(v) Because of light weight and simplicity due to the absence of valve actuating mechanism, initial cost of the engine is less.
(vi) Higher volumetric efficiency due to more time for mixture intake.	vi) Lower volumetric efficiency due to lesser time for mixture intake.
(vii) Thermal efficiency is higher; part load efficiency is better.	Thermal efficiency is lower; part load efficiency is poor.
viii) Used where efficiency is important, viz., in cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.	viii) Used where low cost, compactness and light weight are important, viz., in mopeds, scooters, motorcycles, hand sprayers etc.

1.8 ENGINE PERFORMANCE PARAMETERS

The engine performance is indicated by the term *efficiency*, η. Five important engine efficiencies and other related engine performance parameters are:

(i)	Indicated thermal efficiency	(η_{ith})
(ii)	Brake thermal efficiency	(η_{bth})
(iii)	Mechanical efficiency	(η_m)
(iv)	Volumetric efficiency	(η_v)
(v)	Relative efficiency or Efficiency ratio	(η_{rel})
(vi)	Mean effective pressure	(p_m)
(vii)	Mean piston speed	$(\overline{s}_p)$
(viii)	Specific power output	(P_s)
(ix)	Specific fuel consumption	(sfc)
(x)	Inlet-valve Mach Index	(Z)
(x)	Fuel-air or air-fuel ratio	$(F/A$ or $A/F)$
(xi)	Calorific value of the fuel	(CV)

Figure 1.15 shows the diagrammatic representation of energy distribution in an IC engine.

1.8.1 Indicated Thermal Efficiency (η_{ith})

Indicated thermal efficiency is the ratio of energy in the indicated power, *ip*, to the input fuel energy in appropriate units.

$$\eta_{ith} \quad = \quad \frac{ip \text{ [kJ/s]}}{\text{energy in fuel per second [kJ/s]}} \tag{1.3}$$

1.8.2 Brake Thermal Efficiency (η_{bth})

Brake thermal efficiency is the ratio of energy in the brake power, bp, to the input fuel energy in appropriate units.

$$\eta_{bth} = \frac{bp}{\text{Mass of fuel/s} \times \text{ calorific value of fuel}} \tag{1.5}$$

1.8.3 Mechanical Efficiency (η_m)

Mechanical efficiency is defined as the ratio of brake power (delivered power) to the indicated power (power provided to the piston) or can be defined as the ratio of the brake thermal efficiency to the indicated thermal efficiency.

$$\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp} \tag{1.6}$$

$$fp = ip - bp \tag{1.7}$$

1.8.4 Volumetric Efficiency (η_v)

This is one of the very important parameters which decides the performance of four-stroke engines. Four-stroke engines have distinct suction stroke, volumetric efficiency indicates the breathing ability of the engine. It is to be noted that the utilization of the air is that determines the power output of the engine. Intake system must be designed in such a way that the engine must be able to take in as much air as possible.

Volumetric efficiency is defined as the ratio of actual volume flow rate of **air** into the intake system to the rate at which the volume is displaced by the system.

$$\eta_v = \frac{\dot{m}_a/\rho_a}{V_{\text{disp}}N/2} \tag{1.8}$$

where ρ_a is the inlet density.

1.8.5 Relative Efficiency or Efficiency Ratio (η_{rel})

Relative efficiency or efficiency ratio is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle. The efficiency ratio is a very useful criterion which indicates the degree of development of the engine.

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air-standard efficiency}} \qquad (1.10)$$

1.8.6 Mean Effective Pressure (p_m)

Mean effective pressure is the average pressure inside the cylinders of an internal combustion engine based on the calculated or measured power output. It increases as manifold pressure increases. For any particular engine, operating at a given speed and power output, there will be a specific indicated mean effective pressure, *imep*, and a corresponding brake mean effective pressure, *bmep*. They are derived from the indicated and brake power respectively. For derivation see Chapter 16. Indicated power can be shown to be

$$ip = \frac{p_{im} LAnK}{60 \times 1000} \qquad (1.11)$$

then, the indicated mean effective pressure can be written as

$$p_{im} = \frac{60000 \times ip}{LAnK} \qquad (1.12)$$

Similarly, the brake mean effective pressure is given by

$$p_{bm} = \frac{60000 \times bp}{LAnK} \qquad (1.13)$$