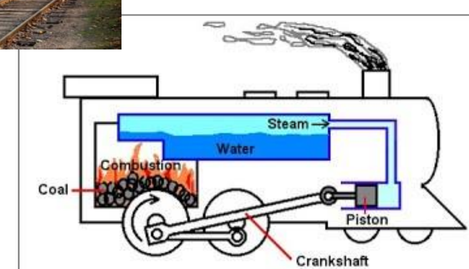
Elements of Mechanical Engineering

Internal Combustion Engines

An **engine** or **motor** is machine designed to convert one form of energy into mechanical energy

The **internal combustion engine** is an engine in which the combustion of a fuel (generally, fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber.

An **external combustion engine** (**EC engine**) is a heat engine where a working fluid, contained internally, is heated by combustion in an external source, through the engine wall or a heat exchanger.



I C Engines

- An internal combustion engine is a device in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work.

Examples:

  - Piston Engines
  - Gas Turbine Engines (Open Cycle)
  - Rocket Engines

History of IC engines:

1700s - Steam engines (external combustion engines)

1860 - Lenoir engine (η = 5%)

1867 - Otto-Langen engine (η = 11%, 90 RPM max.)

1876 - Otto four stroke “spark ignition” engine (η = 14%, 160 RPM max.)

1880s - Two stroke engine

1892 - Diesel four stroke “compression ignition” engine

1957 - Wankel “rotary” engine

The first internal combustion engine to be produced commercially was invented by **Jean Joseph Etienne Lenoir**

In 1860 he patented a gas-fired, single-cylinder internal combustion engine that he mounted to a three-wheeled carriage (coal gas-powered machine).

In a demonstration in Paris, the carriage covered a distance of 7 miles in about 3 hours, which amounts to an average speed of 2 mph.

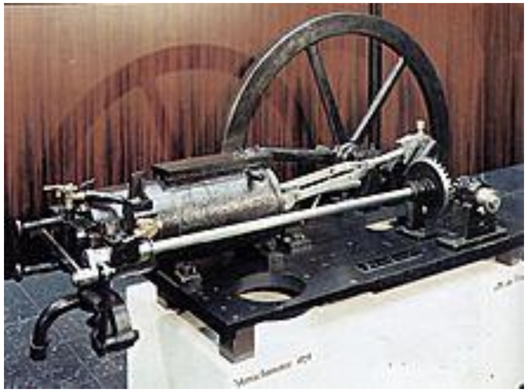
What was so impressive about a carriage that moved so slowly?

Well, the fact that it is powered by an engine and not a horse !!!

Nikolaus August Otto and his brother learned Lenoir engine.

The brothers built a copy of the Lenoir engine and applied for a patent in January 1861 for a liquid fueled engine based on the Lenoir (Gas) engine with the Prussian Ministry of Commerce, but it was rejected.

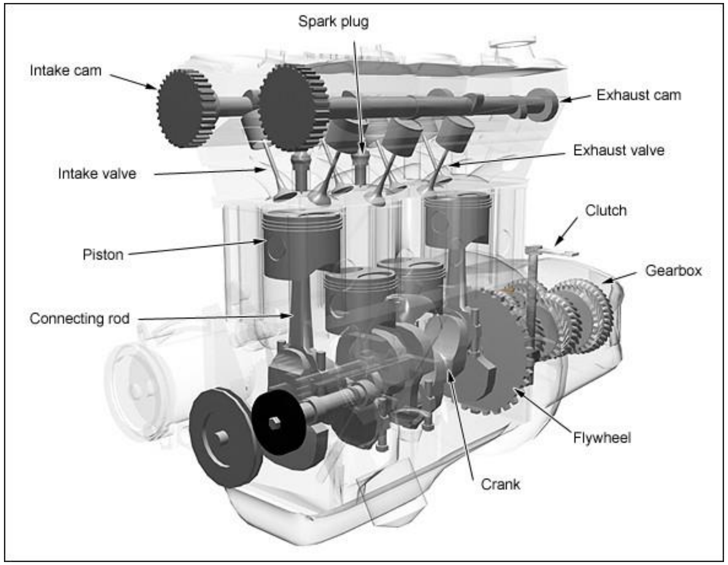
In 1876 Otto built an internal-combustion engine utilizing the four-stroke cycle (four strokes of the piston for each ignition)

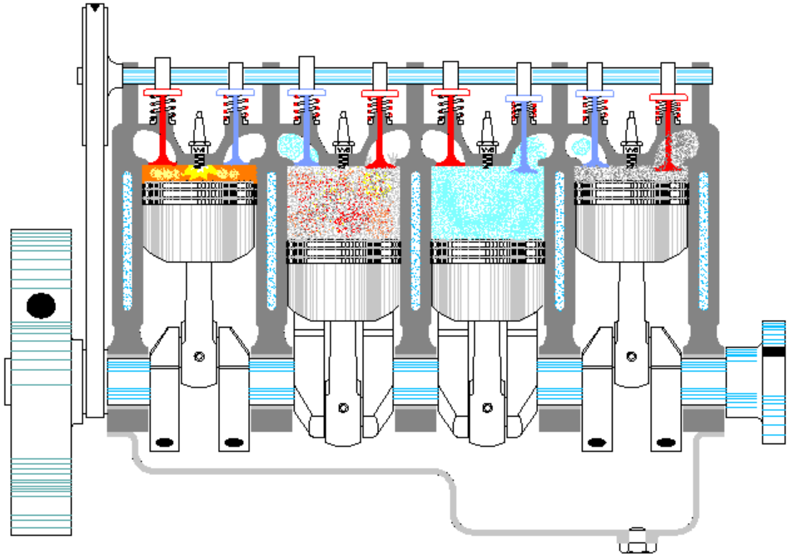


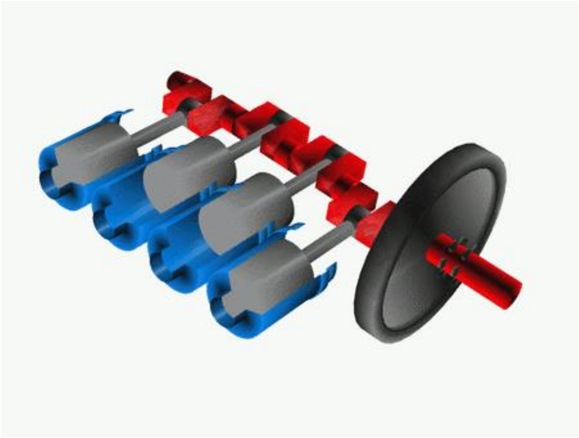
Because of its reliability, its efficiency, and its relative quietness, Otto’s engine was an immediate success.

More than 30,000 of them were built during the next 10 year

Construction of IC Engine







The piston transmits the power developed to the crank shat through connecting rod

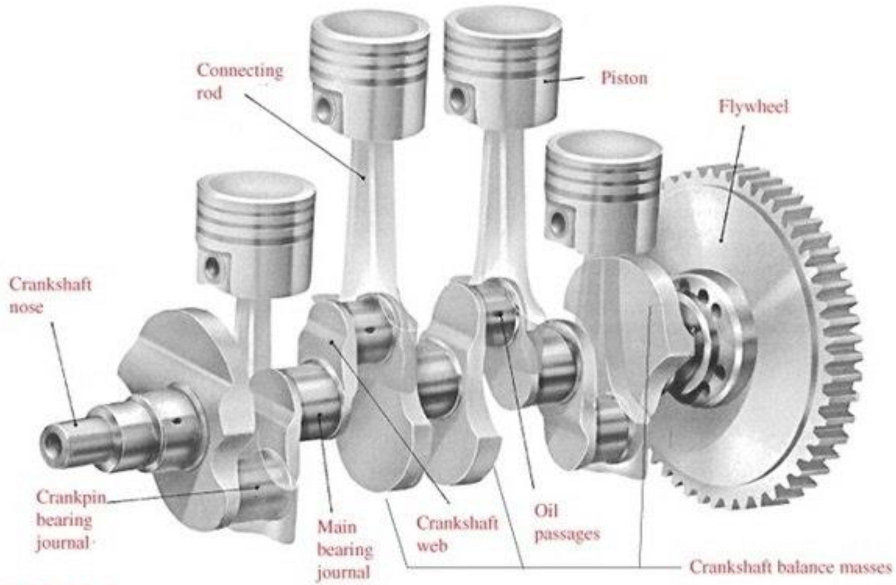


FIGURE 14-3

Crankshaft from an inline four-cylinder engine with pistons, connecting rods, and flywheel

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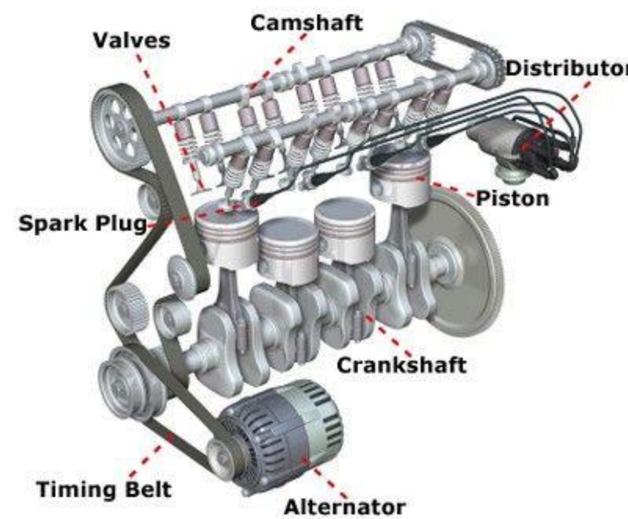
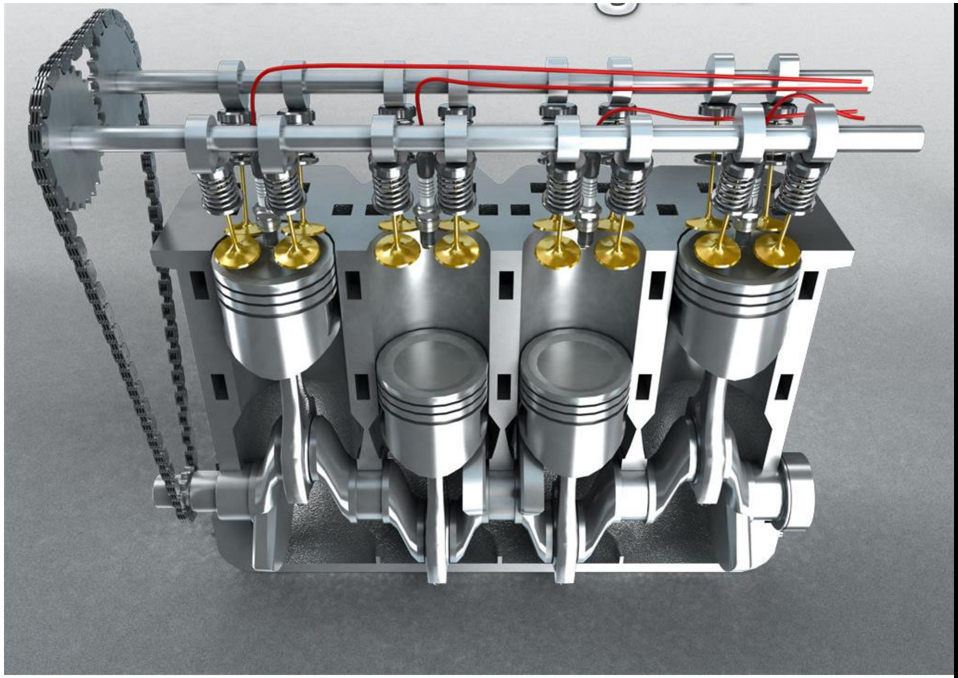
Connecting rod converts the rectilinear motion to rotary motion of the crank shaft

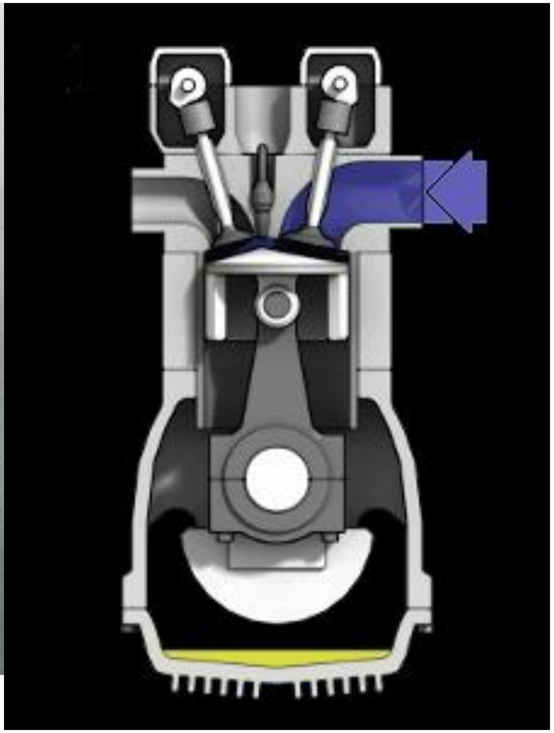
Flywheel is a mechanical energy storage device. Ensures uniform RPM

Piston ring prevents leakage and helps in cooling



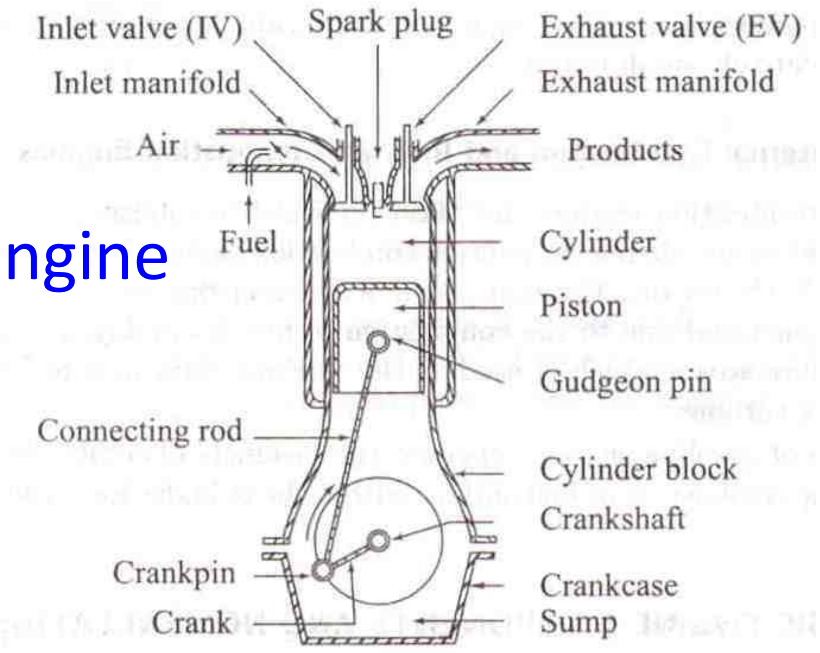
Valves



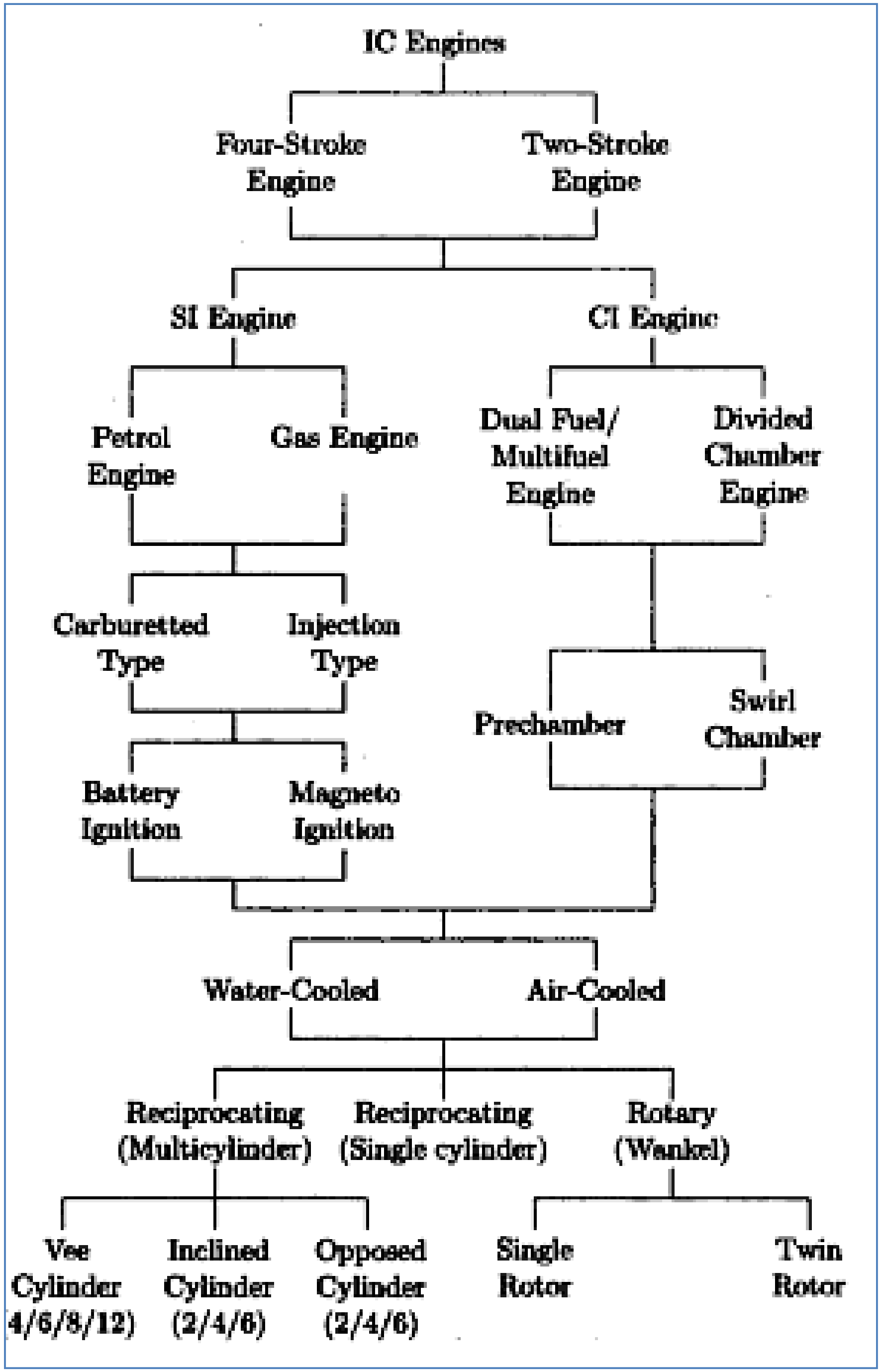


Valves helps the intake air and exit of the combustion products

- The other major components of the engine unit are
  1. Cylinder, cylinder liner and cylinder head
  2. Crank case and oil pan
  3. Lubrication system
  4. Cooling system
  5. Ignition system in SI engine
  6. Fuel supply system

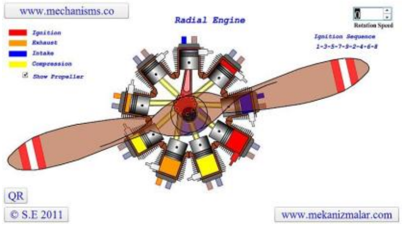


Classification of I C Engines



1. Application

1. Automotive: (i) Car
   (ii) Truck/Bus
   (iii) Off-highway



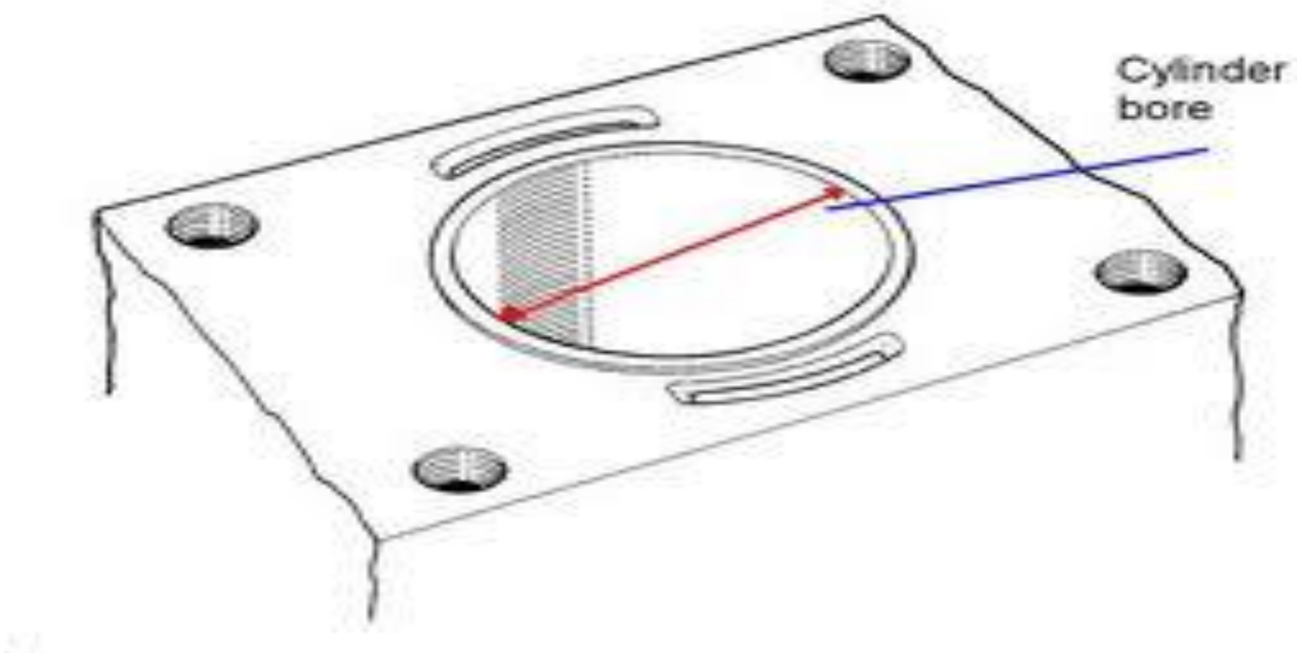
2. Locomotive
3. Light Aircraft
4. Marine: (i) Outboard
   (ii) Inboard
   (iii) Ship
5. Power Generation: (i) Portable (Domestic)
   (ii) Fixed (Peak Power)

6. Agricultural: (i) Tractors
   (ii) Pump sets
7. Earthmoving: (i) Dumpers
   (ii) Tippers
   (iii) Mining Equipment

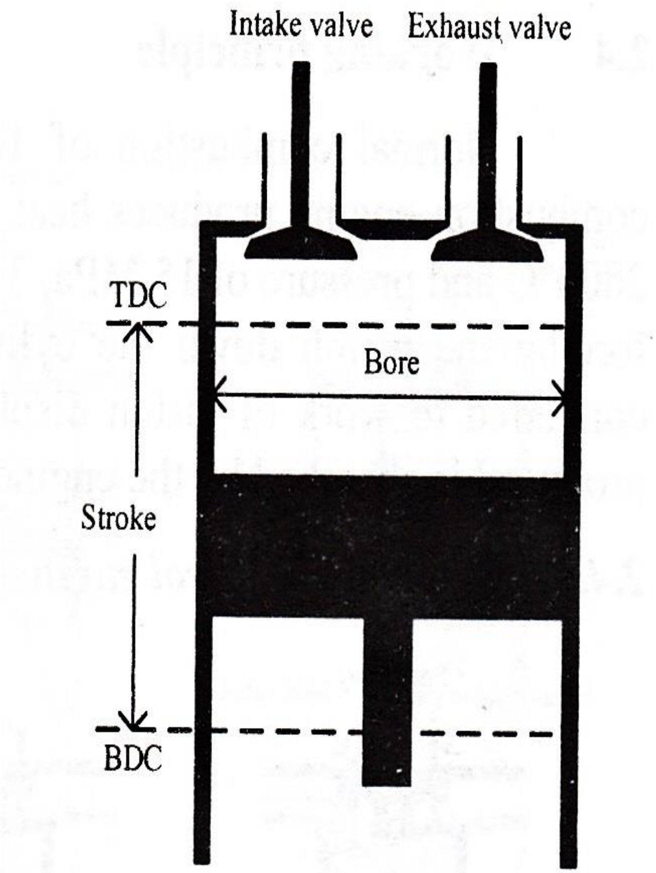
8. Home Use: (i) Lawnmowers
   (ii) Snow blowers
   (iii) Tools

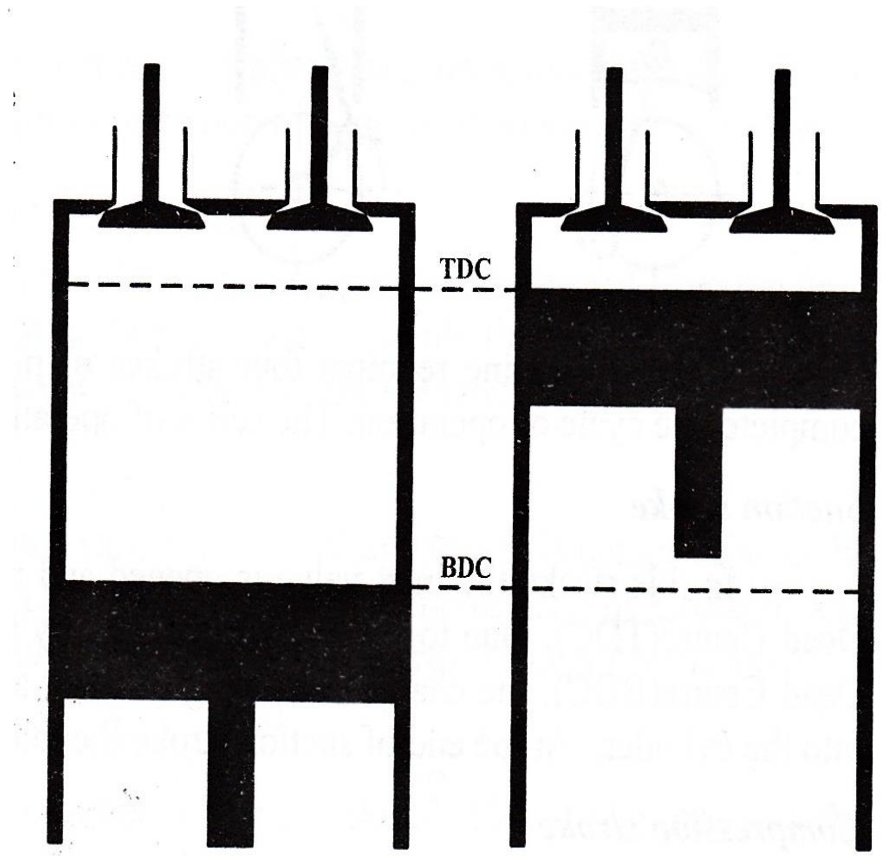
Engines

ENGINE NOMENCLATURE - BORE

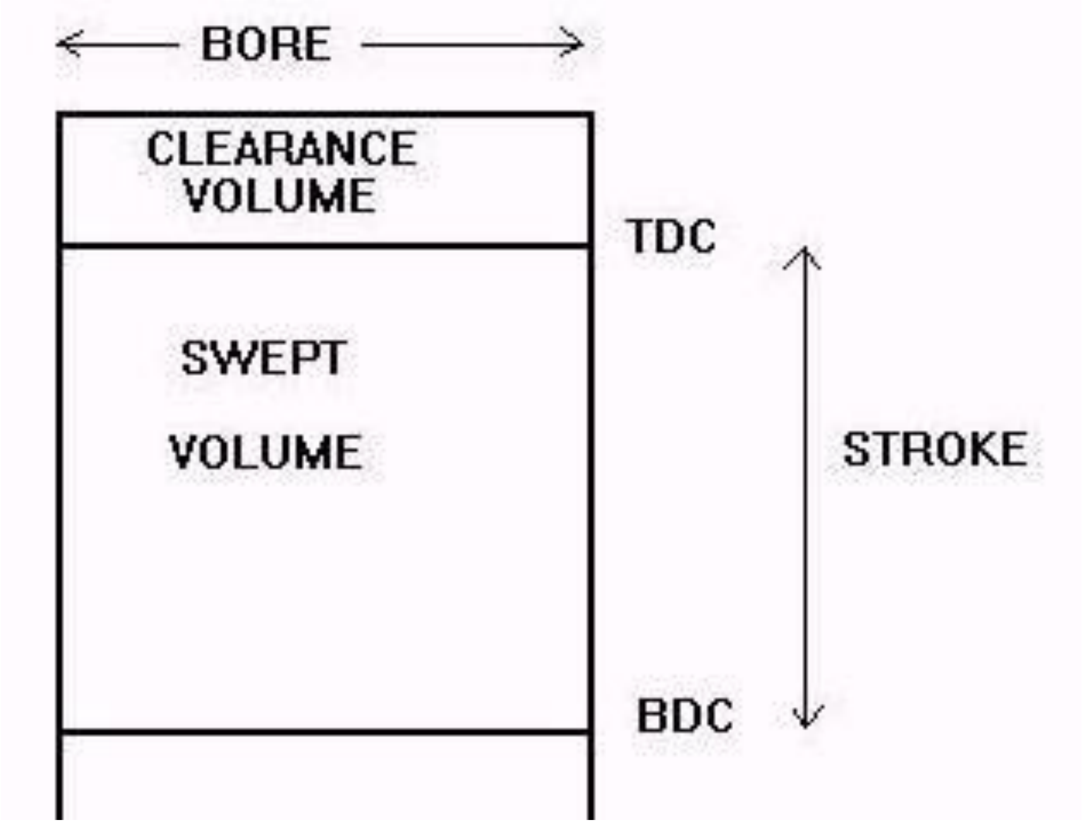


TDC – BDC - STROKE

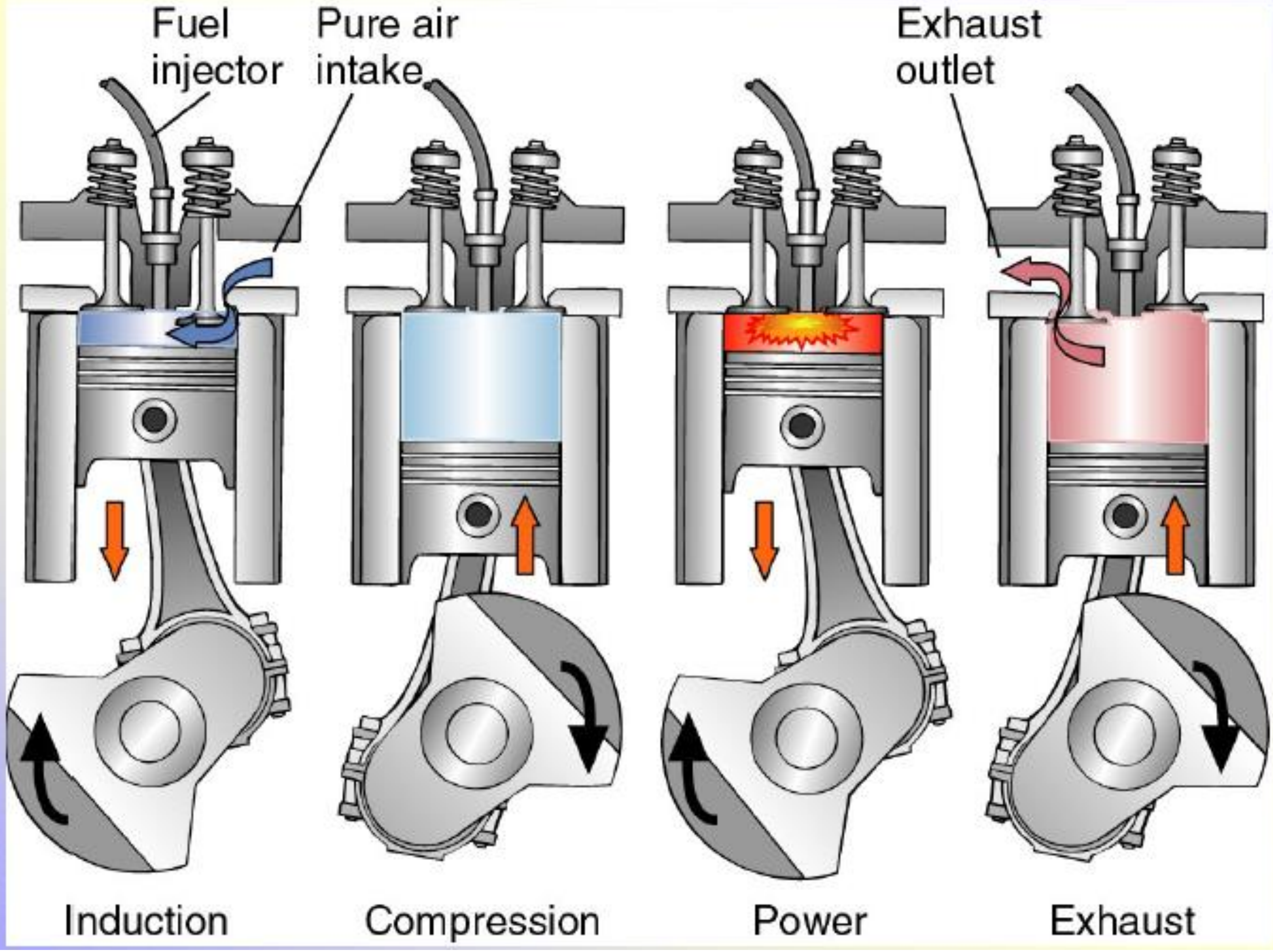




SWEPT VOLUME & CLEARANCE VOLUME



$$\text{COMPRESSION RATIO} = \frac{(\text{Swept Volume} + \text{Clearance Volume})}{\text{Clearance Volume}}$$


Fuel injector
Pure air intake
Exhaust outlet
Induction
Compression
Power
Exhaust

Four stroke spark ignition engines

a) **Suction Stroke**: Fresh charge (Air+fuel) enters in to the cylinder as piston moves from TDC to BDC

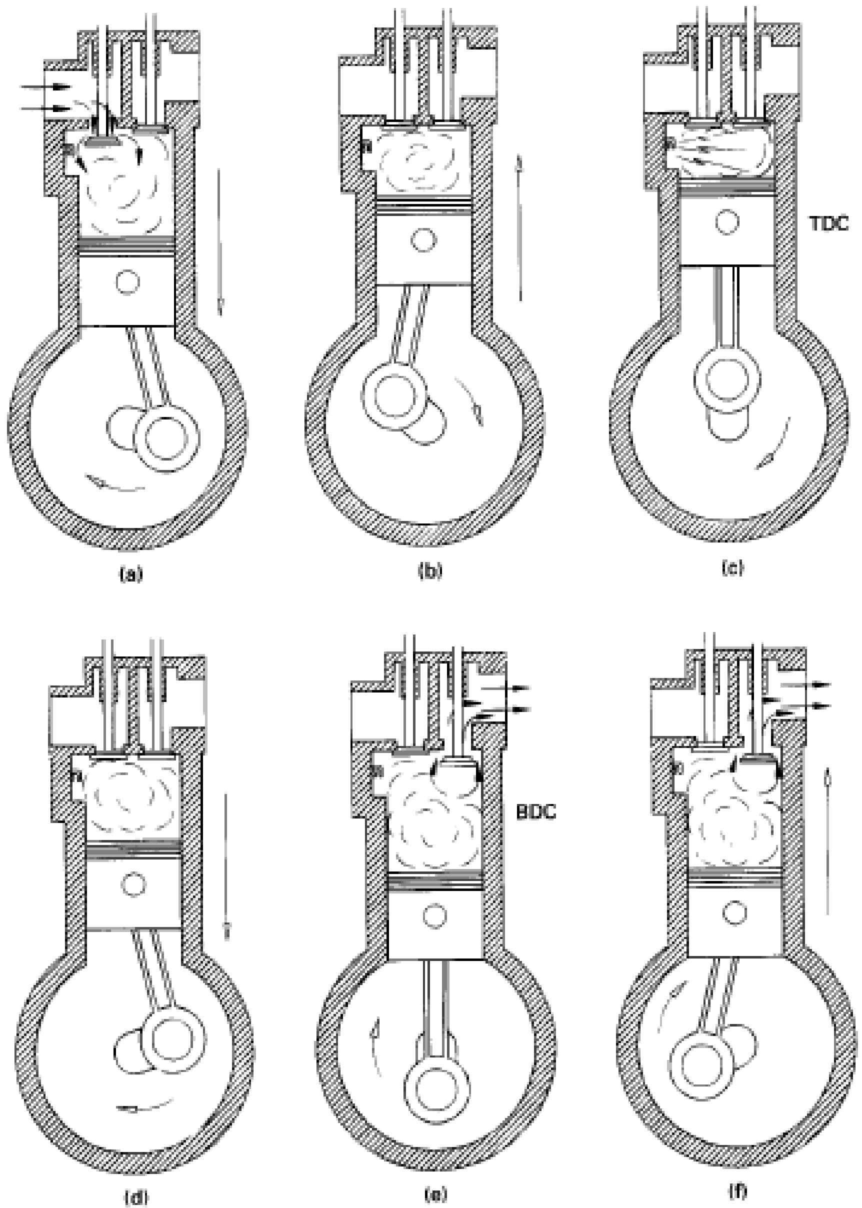
b) **Compression Stroke:-** piston moves from BDC to TDC. Spark ignition occurs at the end of compression stroke.

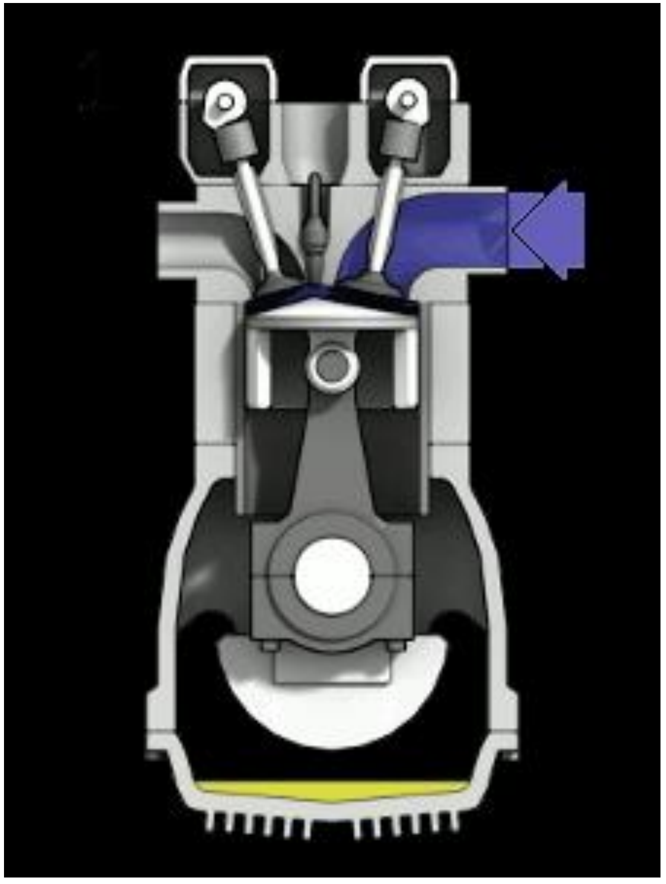
c) **Combustion:** at almost constant volume near TDC.

d) **Power stroke:** high cylinder pressure pushes piston from TDC to BDC

e) **Exhaust blow down:** when exhaust valve opens near the end of power stroke

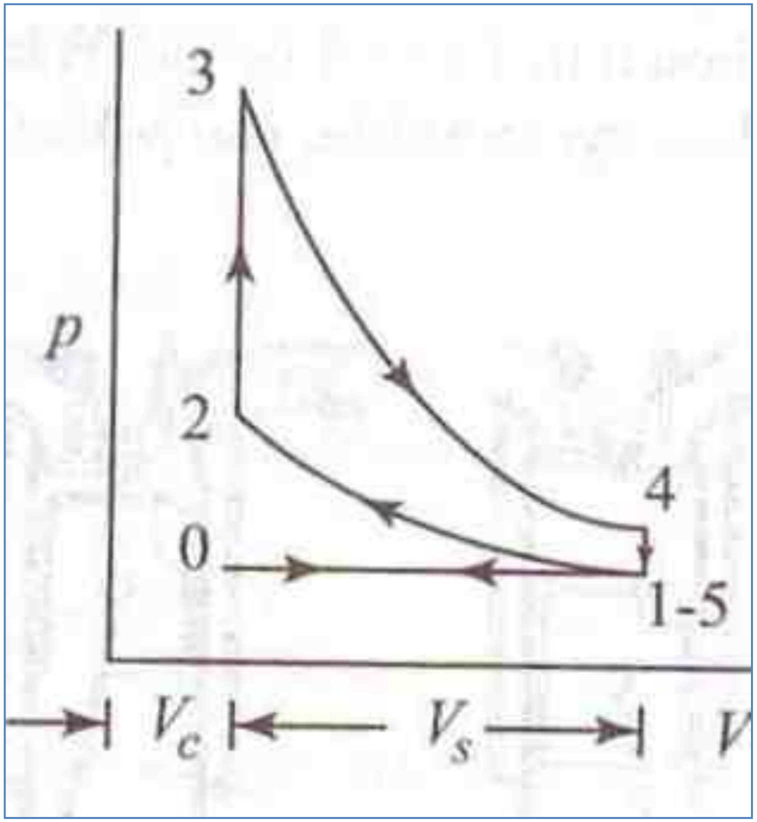
f) **Exhaust stroke:** Piston moves from BDC to TDC, pushes combustion products through exhaust valve





How Gasoline Engine Works

Four stroke spark ignition engines



Ideal P-V diagram

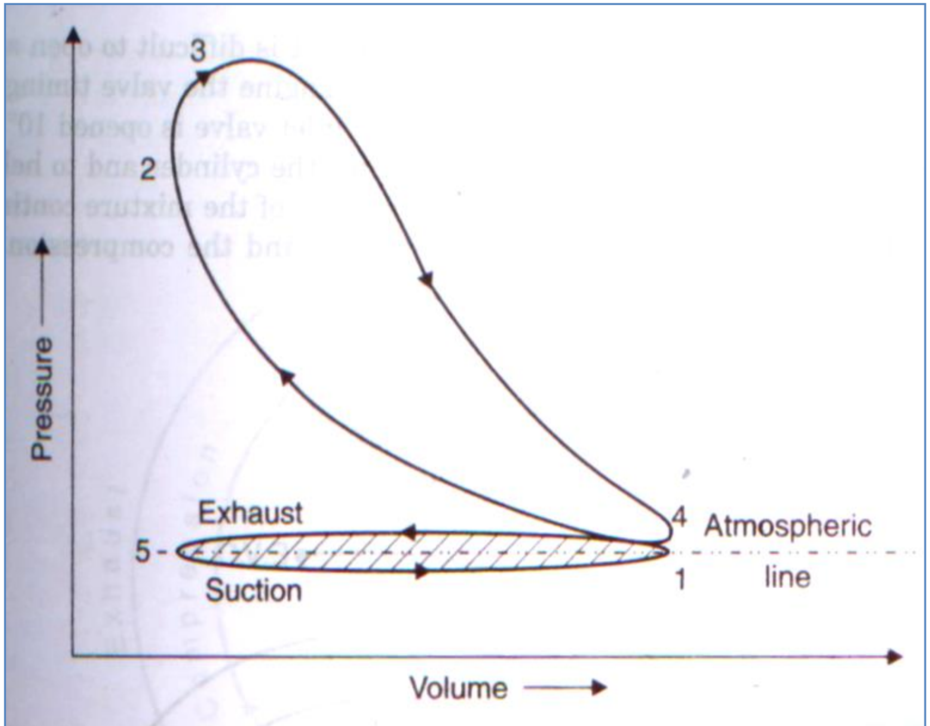
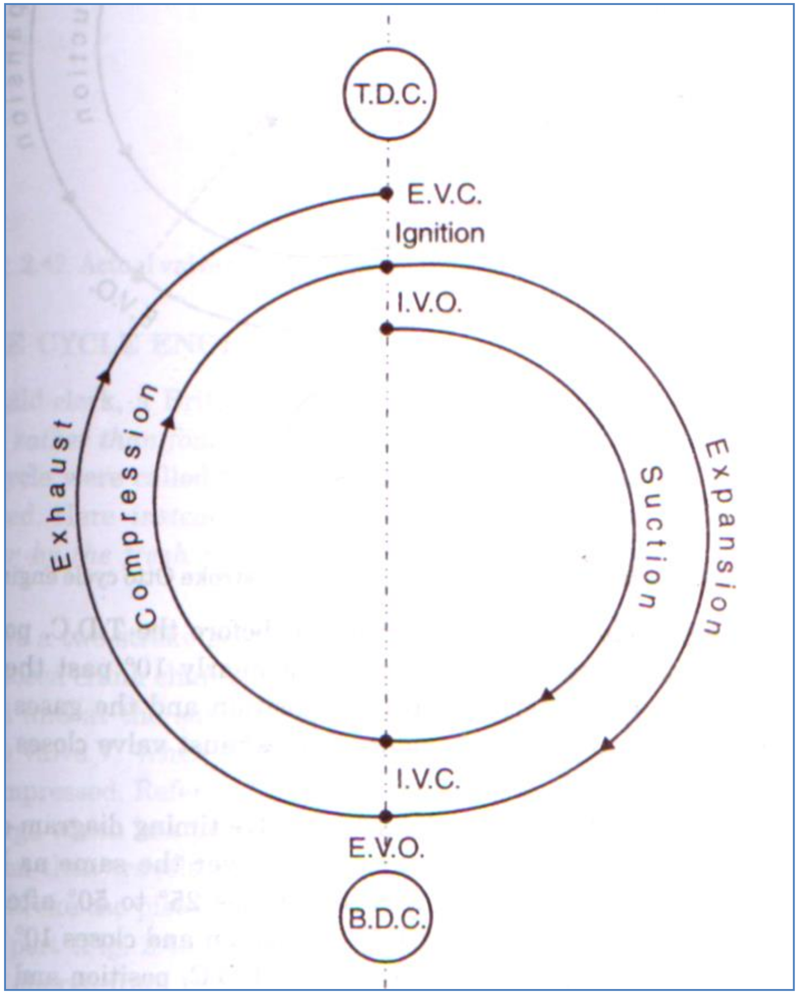


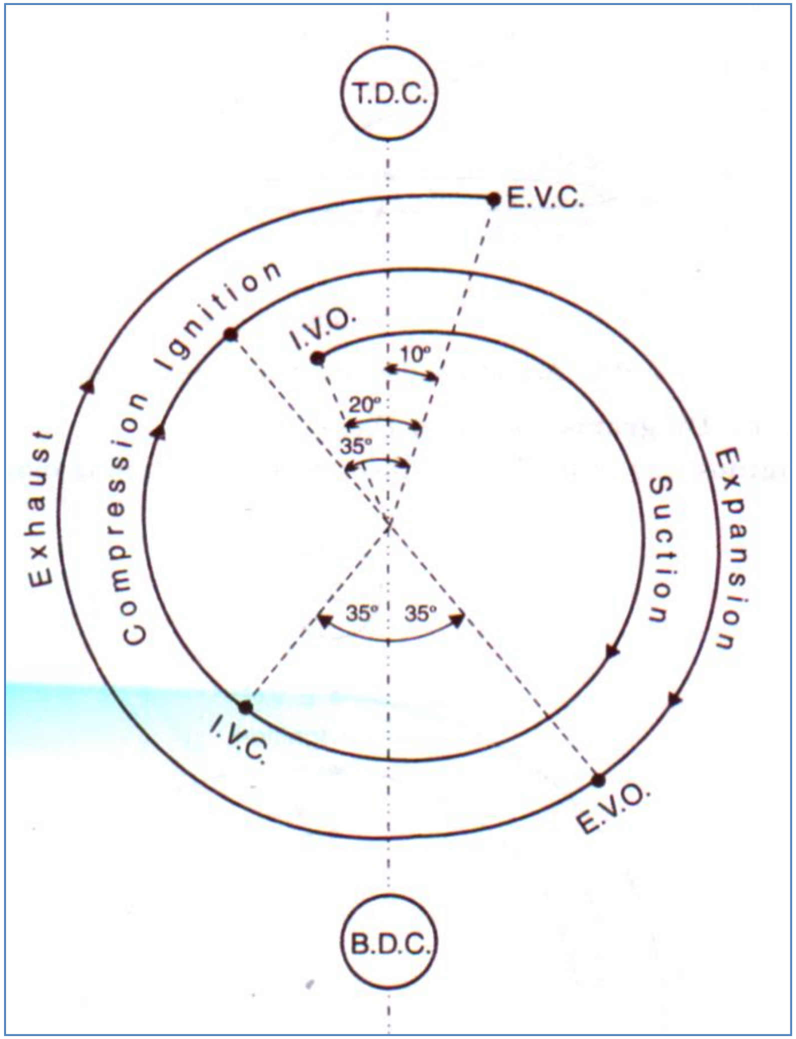
Fig. 2.39. Actual p-V diagram of four stroke Diesel cycle.

Actual P-V diagram

Four stroke spark ignition engines

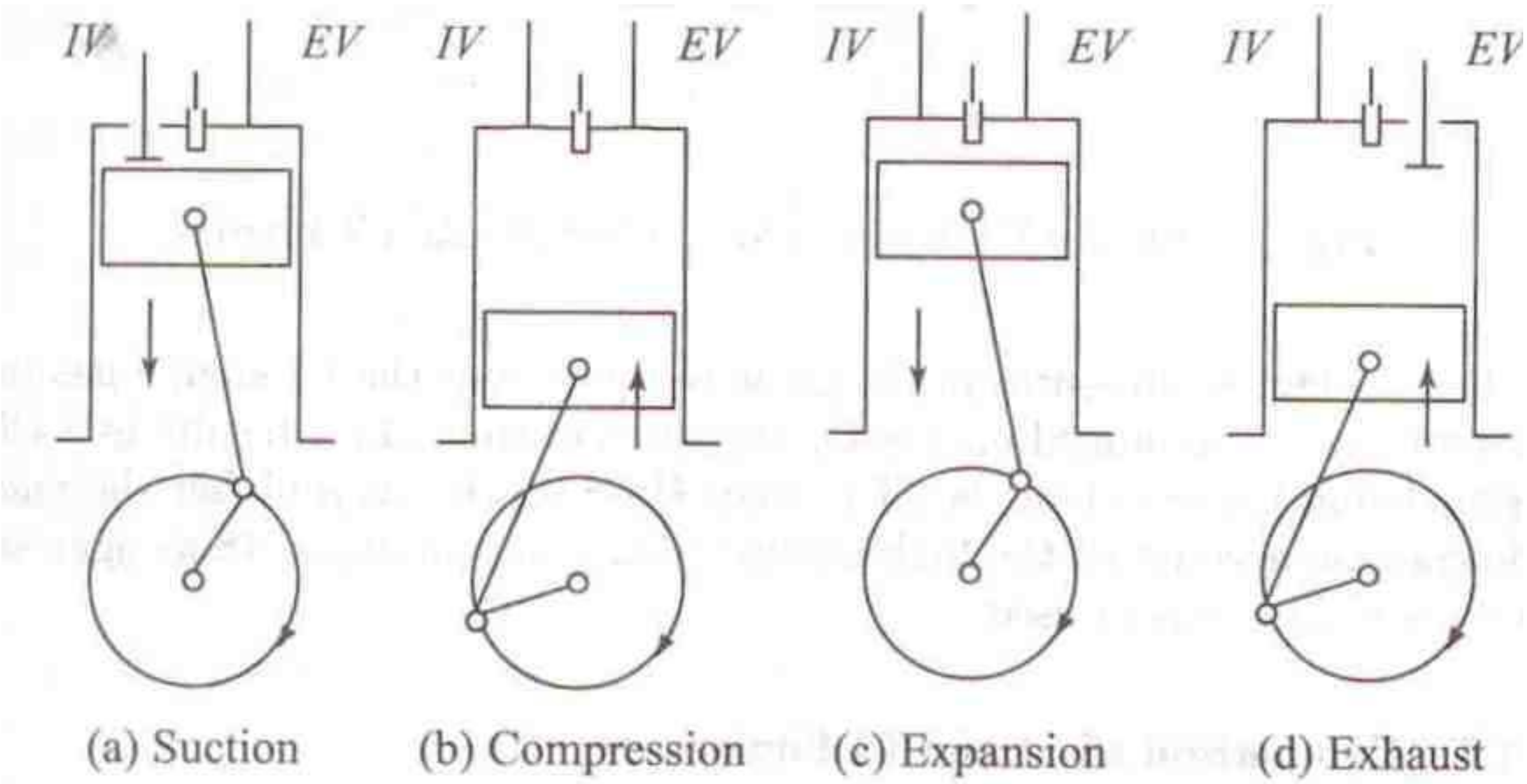


Ideal Valve Time Diagram

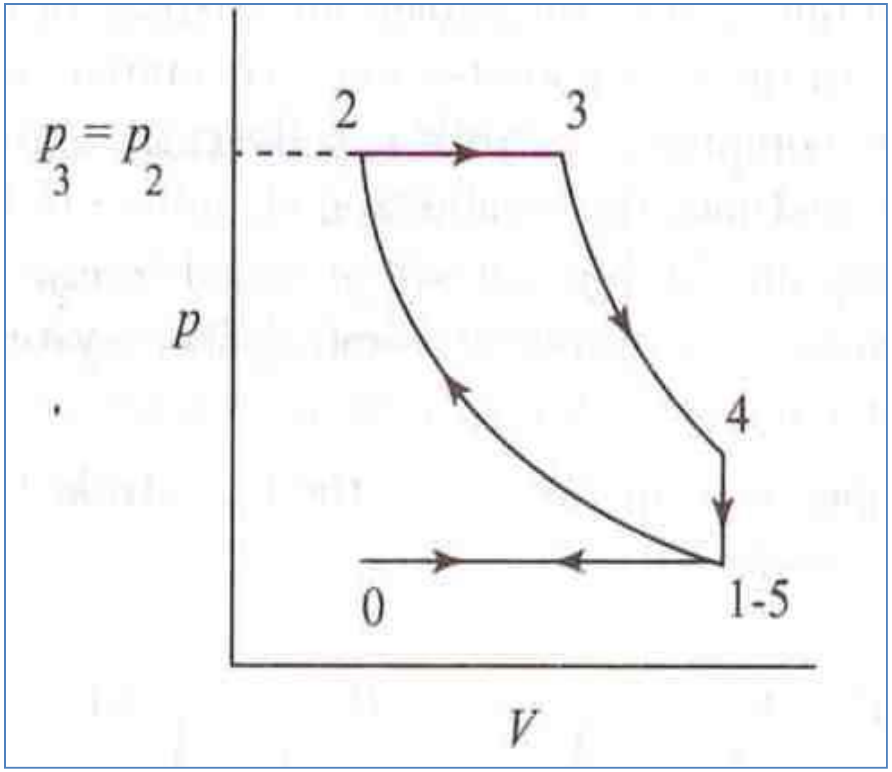


Actual Valve Time Diagram

Four stroke C I engines



Four stroke C I engines



- Invented by Rudolf Diesel (1892)
- Higher compression ratio
- Charge is air alone, no carburetor.
- Self ignition, no spark plug
- Fuel is injected using fuel pump and injector

Two stroke SI engines

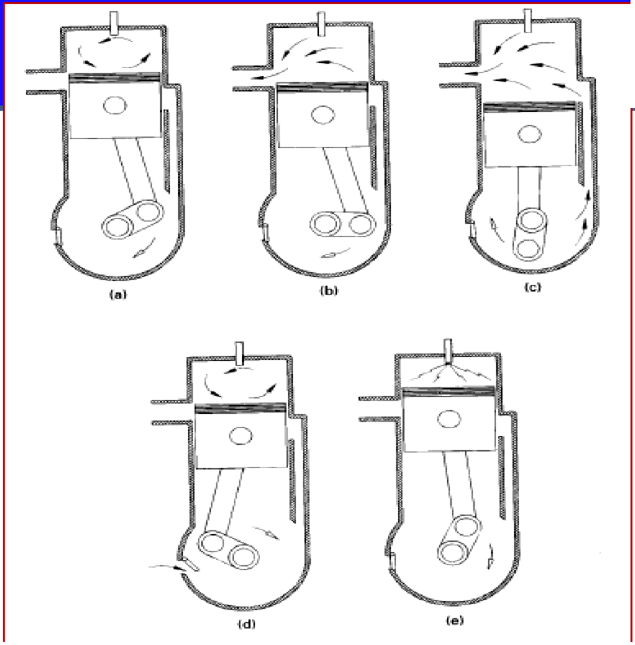
a) **Power Stroke**: High pressurized charge inside the cylinder pushes piston from TDC to BDC with all ports closed. Charge in the crankcase will be compressed by downward motion of piston.

b) **Exhaust blow down** when exhaust port opens near the end of the power stroke.

c) **Cylinder scavenging:-** when piston uncovers transfer port, fresh charge will enter in to the cylinder under pressure. Fresh charge pushes some of the remaining exhaust through exhaust port.

d) **Compression stroke**: Piston moves from BDC to TDC, fresh charge fills the crankcase

e) **Combustion** at TDC with constant volume.



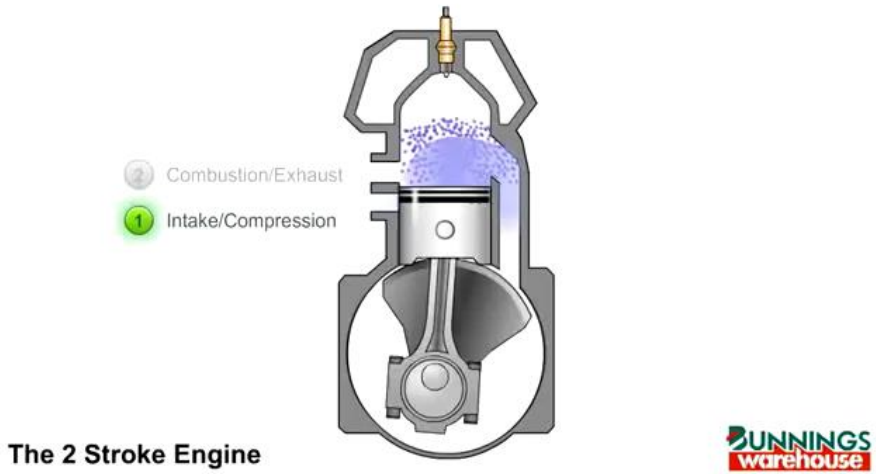
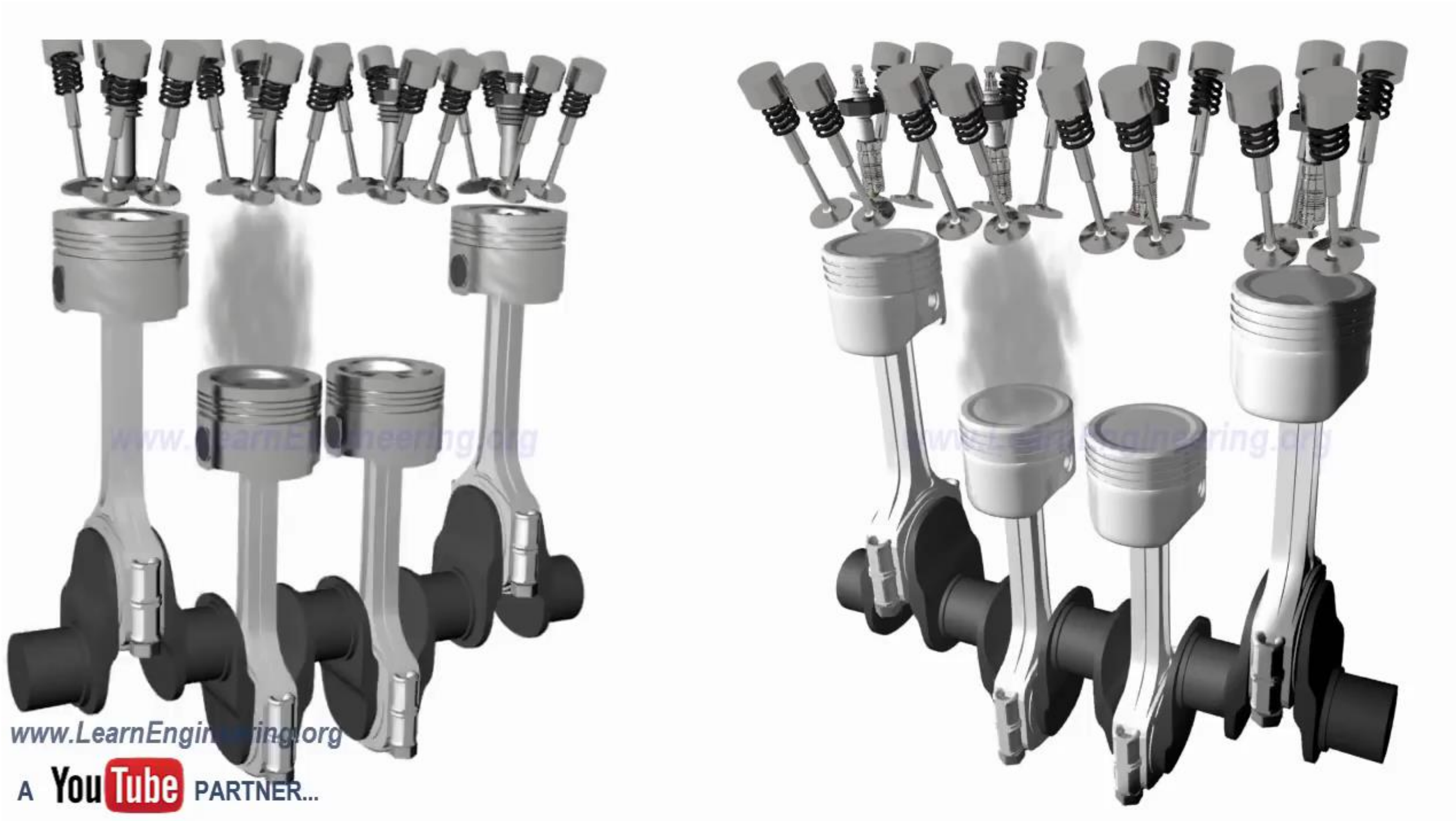


Table 1.1 Comparison of SI and CI Engines

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 introduced.	The quantity of fuel is regulated. 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 lower peak pressures.	Heavier due to higher peak pressures.

FOUR STROKE ENGINE	TWO STROKE ENGINE
1. One cycle in 4 strokes of piston or 2 revolutions of crankshaft	1. One cycle in 2 strokes of piston or one revolution of crankshaft
2. Valves are used for charge admission and exhaust	2. No valves but ports are used for admission and exhaust
3. One power stroke in two revolution causing torque fluctuations needing heavy flywheel	3. One power stroke in one revolution causing smoother torque and consequent lighter flywheel
4. Low power to weight ratios	4. Higher power to weight ratios
5. Higher overall efficiency	5. Lower overall efficiency due to loss of fresh charge
6. Complex construction due to valve gear	6. Simpler construction
7. Heavy duty applications	7. Light duty applications


A YouTube PARTNER...

Firing order

- Firing order refers to the sequence in which the charge in the various cylinders of a multi cylinder engine is ignited and burnt.
- Cylinders are ignited at the alternative ends of the crankshaft. This enables the crankshaft to be stressed more or less uniformly along its length.
- When designing an engine, choosing an appropriate firing order is critical
    - to minimizing vibration,
    - to improve engine balance and
    - achieving smooth running,
    - for long engine fatigue life and user comfort,
    - heavily influences crankshaft design.

number of cylinders	firing order	example
3	1-2-3 1-3-2	Saab two-stroke, Perodua Kancil engine BMW K75 engine, Subaru Justy engine
4	1-3-4-2 1-2-4-3 1-3-2-4 1-4-3-2	Most straight-4s, Ford Taunus V4 engine Some British Ford and Riley engines, Ford Kent engine, Riley Nine Subaru 4-cylinder engines, Yamaha R1 crossplane Volkswagen air-cooled engine
5	1-2-4-5-3 1-3-5-4-2	Straight-five engine, Volvo 850, Audi 100 GM Atlas engine
6	1-5-3-6-2-4 1-4-3-6-2-5 1-6-5-4-3-2 1-2-3-4-5-6 1-4-2-5-3-6 1-4-5-2-3-6 1-6-3-2-5-4	AMC straight-6 engine, Chrysler Slant-6 engine, Mercedes-Benz M104 engine, Maserati 3500 GT I6, Volkswagen VR6 engine, Opel Omega A, Nissan L Engine Mercedes-Benz M272 engine, Volkswagen V6's (both engines are 90-degree V6's) GM 3800 engine, Rover KV6 engine General Motors 60° V6 engine, Mazda JE 3.0 litre 60-degree V6 engine, Chrysler Pentastar engine, Ford Cologne V6 engine, Ford Essex V6 engine (UK) Chevrolet Corvair

Performance – IC Engines

Terminology

- **Top dead center**:- Farthest point of forward travel of the piston in the cylinder.
- **Stroke (L)**:- Distance between TDC and BDC, travelled by the piston in the cylinder
- **Bore (D)**:- Inside diameter of the cylinder
- **Throw (R):-** Distance between the center of the crank shaft main bearing to the center of the crank pin or connecting rod bearing. Throw is the half of the stroke length.

$$L = 2R$$

Terminology

- **Clearance volume (V_c)**:- volume of the cylinder above the piston when the piston is at TDC.

- **Displacement volume (V_d)**:- volume displaced by the piston between TDC and BDC.

- **Total Volume (V_t)**:- $V_c + V_d$

- **Compression ratio:-** ratio of total volume of the cylinder to clearance volume

Power and MEP

- **Indicated power (IP)**:- net power actually developed at the piston face during the events of mechanical cycle. Name derived because it is determined by the instrument called an 'Engine indicator'

$$IP = \frac{p_i L A n}{60{,}000}, \text{ for single cylinder engine, kW,}$$

$$= \frac{p_i L A n}{60{,}000} \times \text{ no. of cylinders, for multi-cylinders engine, kW,}$$

L= Length of the stroke

A = C/S area of the cylinder

n = No of power impulses /min

p_i = IMEP

Power and MEP

- **Indicated Mean Effective Pressure (IMEP)**:

  ✓ Algebraic sum of the mean pressures acting on the piston during each stroke over one complete cycle.

  ✓Pressure are positive when acting in the direction of piston movement and vice versa

  ✓ It is measured through the help of indicator diagram drawn with help of engine indicator

Indicated Power is the power produced inside the cylinder of an engine. It is calculated by finding the actual mean effective pressure. The actual mean effective pressure is found as follows.

Let a = Area of the actual indicator diagram, sq.cm

l = Base width of the indicator diagram, cm

s = Spring Value of the spring used in the indicator, $N/m^2/cm$

P_{mep} = Actual Mean Effective Pressure, N/m^2

$$\boxed{P_{mep} = \frac{sa}{l}\ N/m^2}$$

The indicated power of the four stroke and two stroke engines are found as follows:

Let P_{mep} = Mean Effective Pressure, N/m^2

L = Length of Stroke, m

A = Area of Cross section of the Cylinder, sq m

N = RPM of the Crankshaft.

n = No. of cycles /min

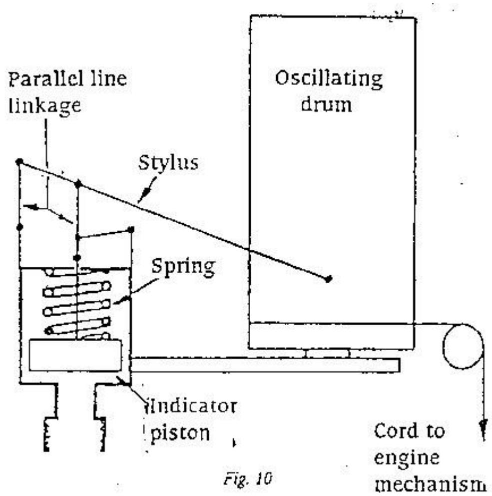


Fig. 10

Power and MEP

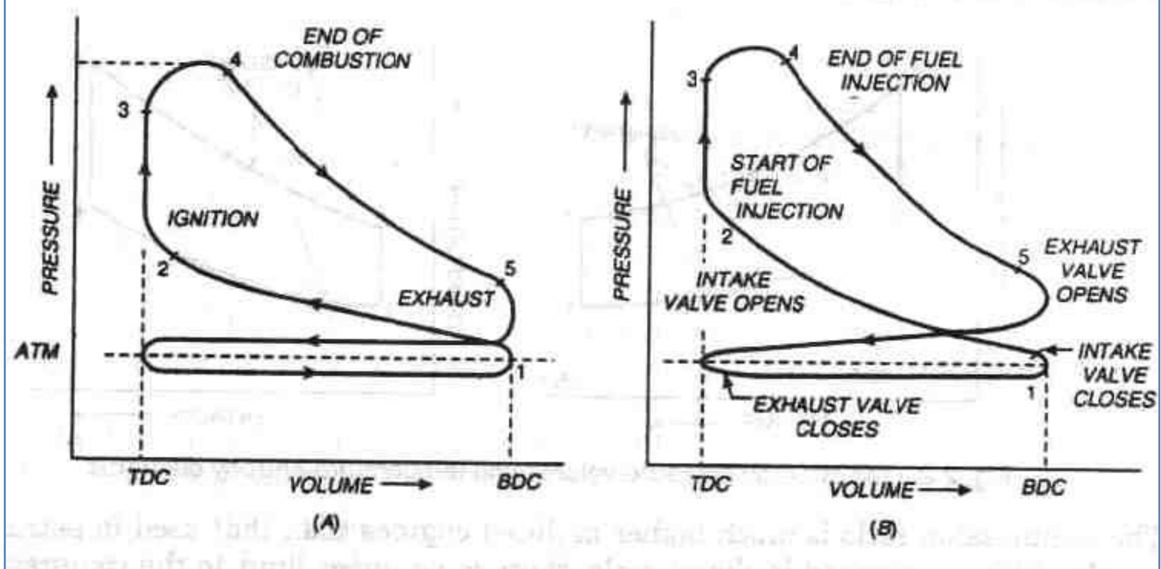


Fig. 2.5. Actual pressure-volume diagrams for four stroke engines. A. Petrol engine. B. Diesel engine.

Indicator Diagram

Power and MEP

- **Brake power:** Actual work output available at the crank shaft and is termed so because it can be obtained by absorbing the power output by means of brake.

$$BP = \frac{2\pi NT}{60{,}000}, \text{ kW},$$

N is crankshaft or engine rpm,

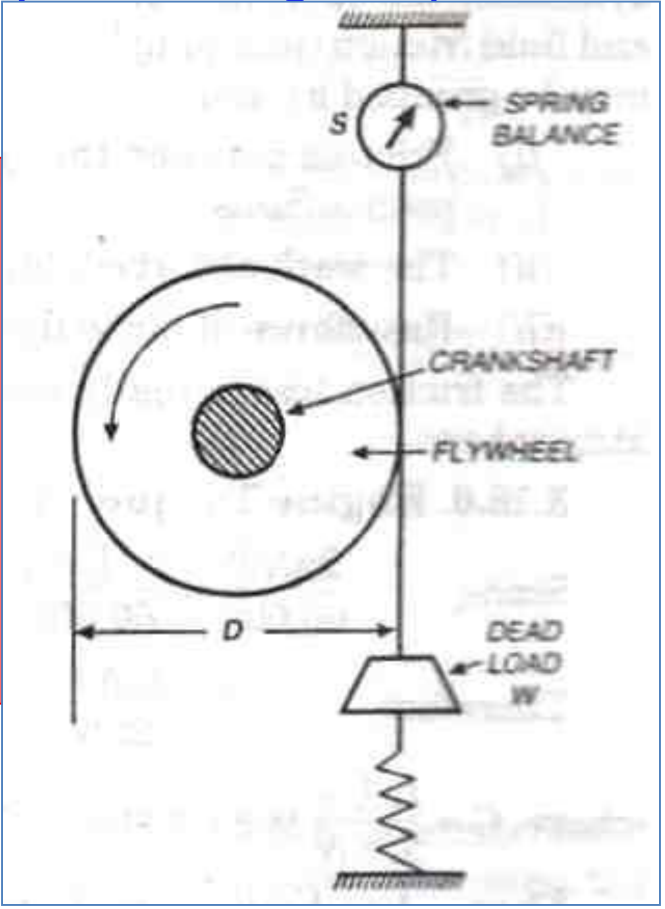
T is torque or resisting torque in the dynamometer,

Resisting torque, $T = (W - S)\, D/2$, Nm,

$W =$ dead load applied, N,

$S =$ spring tension, N,

$D =$ diameter of flywheel, N.



Rope brake dynamometer

Power and MEP

The indicated and mean effective power can be expressed in terms of mean effective pressures

$$IP = \frac{C\,P_m LAN_c}{60 \times 1000}\ \text{kW}$$

where

L is the length of stroke in metre

A is the piston area in square metre

N_c is the number of cycles per minute

Note:

$N_c = N$; N = crank revolution/minute for two-stroke engine.

$N_c = N/2$, N = rpm of engine's crank for four-stroke engine.

C is the number of cylinders in the engine.

The man effective pressure sometimes defined with respect to brake power, as below

$$BP = \frac{CP_{mb} LAN_C}{60 \times 1000}\ \text{kW}$$

Power and MEP

Friction Power

3.18.5. Friction Power (*FP*) of an engine is less than its *IP* owing to frictional losses at the working surfaces like bearings, piston rings and valves. The power lost in this way is known as friction power. Thus,

$$FP = IP - BP.$$

Frictional losses may be grouped as under

(*i*) Friction between the cylinder surface and the piston rings, in bearings, gears, valve mechanisms.

(*ii*) The work absorbed during the exhaust and suction stroke.

(*iii*) Resistance of air to flywheel rotation.

The friction loss is really the transformation of work into heat, which is dissipated to the atmosphere.

Thermal efficiencies

- **Factors on which thermal efficiency depends are**

1. Compression ratio
2. Engine speed
3. Loads
4. Mixture strength
5. Nature of fuel
6. Temperature of cylinder walls

Thermal efficiencies

1. **Indicated thermal efficiency:-** shows what fraction of heat supplied is converted in to indicated work.

i.e. $$\eta_i = \frac{\text{Indicated work in heat units}}{\text{Energy supplied}} = \frac{60\, IP}{w_f\, HV}$$

where, w_f is fuel supplied, kg/min,

and HV is heating value of fuel, kJ/kg.

2. **Brake thermal efficiency:-** shows fraction of heat supplied that is transformed in to shaft work.

$$\eta_b = \frac{\text{Brake work done in heat units}}{\text{Energy supplied}} = \frac{60\, BP}{w_f\, HV}$$

Fuel Consumption

- ✓ Specific fuel consumption is defined as the total fuel consumption per hour per kW developed.
- ✓ SFC also defined as rate of fuel consumption per kWh.
- ✓ When IP is associated, its called as ISFC
- ✓ When BP is used, its termed as BSFC

$$ISFC = \frac{60\, w_f}{IP} = \frac{3600}{HV\, \eta_i}, \text{ kg/ik Wh.}$$

$$BSFC = 60\, w_f/BP = 3600/(HV\, \eta_b), \text{ kg/bkWh.}$$

Mechanical efficiency

- Ratio of power delivered by the engine to the total power developed within the engine is known as **'Mechanical efficiency'**

$$\eta_m = \frac{BP}{IP}\left(\text{or } \frac{BP}{BP+FP}\right) = \frac{BMEP}{IMEP} = \frac{\eta_b}{\eta_i}$$

Volumetric efficiency

- Ratio of the actual weight of air induced by the engine in the intake stroke to the theoretical weight of air that should have been induced due to piston displacement at the intake pressure and temperature.

$$\eta_v = \frac{\text{Actual air capacity}}{\text{Ideal air capacity}}$$

$$= \frac{\text{Volume of air aspirated at intake conditions per min}}{\text{Stroke volume} \times \text{no. of cylinders} \times n} .$$

Morse Test

- **IP and mechanical efficiency can be found out.**
- **Test procedure:-**

1. **Engine is run at a constant speed and at same throttle opening.**
2. **Dynamometer is used to measure BP, with all cylinder in operating mode.**
3. **BP of the engine is measured with each cylinder rendered inoperative one by one. Engine speed goes down, before taking reading, initial speed must be restored by adjusting the load.**

Morse Test

It is assumed that the FP of the inoperative cylinder remains the same as it were when the cylinder was operative. Considering the case of a 4-cylinder engine,

Let, $B = BP$ of the engine with all cylinders operative.

$B_1 = BP$ of the engine with cylinder no. 1 inoperative.

$B_2 = BP$ of the engine with cylinder no. 2 inoperative.

$B_3 = BP$ of the engine with cylinder no. 3 inoperative.

$B_4 = BP$ of the engine with cylinder no. 4 inoperative.

I_1, I_2, I_3 and $I_4 = IP$ of cylinders 1,2,3 and 4 respectively.

F_1, F_2, F_3 and $F_4 = FP$ of cylinders 1,2,3 and 4 respectively.

Therefore,
$$B = (I_1 - F_1) + (I_2 - F_2) + (I_3 - F_3) + (I_4 - F_4).$$
$$= (I_1 + I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4).$$

When cylinder No. 1 is rendered inoperative, it does not develop any power; on the contrary some power is lost due to movement of piston inside the cylinder. Then,

$$B_1 = (I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4).$$

From the above equations, $B - B_1 = I_1$

Similarly, $B - B_2 = I_2$

$B - B_3 = I_3$

and $B - B_4 = I_4.$

Therefore, total IP of the engine $= I_1 + I_2 + I_3 + I_4 = I$ (say) and mechanical efficiency $= B/I$.

Performance curves

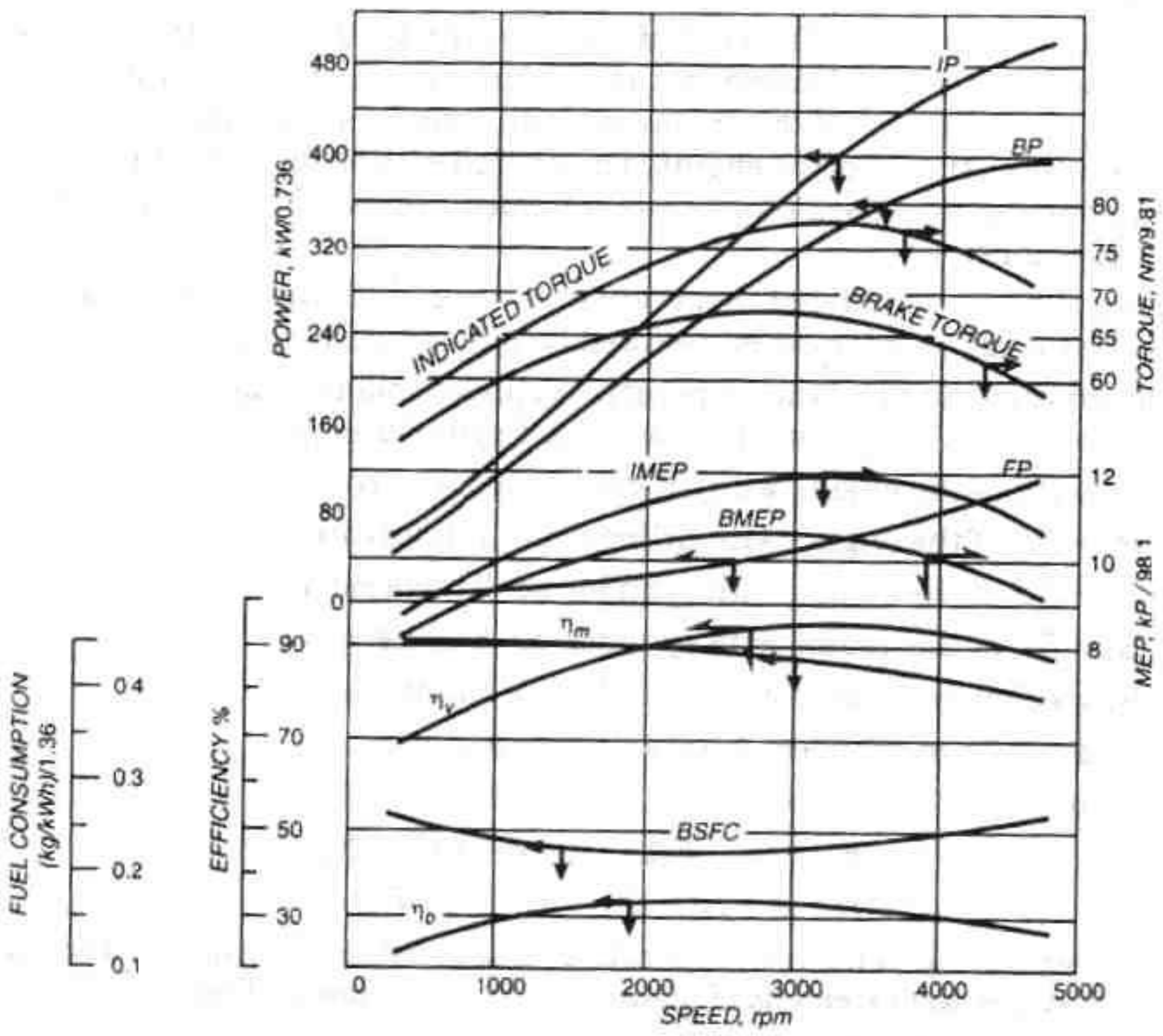


Fig. 3.50. Typical performance curves of automotive SI engine.

EXAMPLE 8.3 For a test on a four-stroke petrol engine, the following data is available: **Speed of engine** = 1000 rpm, net brake torque = 70 N·m, indicative mean effective pressure = **10 bar, stroke** = 150 mm, bore = 100 mm, rate of fuel consumption = 2.57 kg/h, CV of petrol = **41000** kJ/kg. Calculate the indicated thermal efficiency, brake thermal efficiency and mechanical efficiency. [G.U. July, 2003]

Solution $N = 1000$ rpm, $T_b = 70$ N·m, $P_{mi} = 10$ bar, $L = 150$ mm, $D = 100$ mm
$W_f = 2.57$ kg/h, $CV = 41000$ kJ/kg

Assume the number of cylinder = 1, $N_c = \dfrac{1000}{2} = 500$ rpm

$$\therefore \quad \text{IP} = \frac{1 \times P_{mi} \times L \times A \times N_c}{60}$$

$$= \frac{1 \times (10 \times 100) \times \frac{150}{1000} \times \frac{\pi}{4} \times (0.100)^2 \times 500}{60}$$

$$= \frac{150 \times \pi \times 0.1^2 \times 500}{4 \times 60} = 9.81\,\text{kW}$$

$$\text{BP} = \frac{2\pi NT}{60} = \frac{2\pi \times 1000 \times \frac{70}{1000}}{60} = 7.32\ \text{kW}$$

$$\text{Indicated thermal efficiency} = \frac{\text{IP}}{W_f \times \text{CV}} = \frac{9.81}{\frac{2.57}{3600} \times 41000} = \frac{0.3351}{1} = 33.51\%$$ **Ans.**

$$\text{Brake thermal efficiency} = \frac{\text{BP}}{W_f \times \text{CV}} = \frac{7.32}{\frac{2.57}{3600} \times 41000} = 0.2500 = 25\%$$ **Ans.**

$$\text{Mechanical efficiency} = \frac{7.32}{9.81} = 0.7461 = 74.61\%$$ **Ans.**

EXAMPLE 8.24 A six-cylinder, four-stroke compression ignition engine is to develop 90 kW indicative power at 2500 rpm. The stroke to bore ratio is 1.4:1. Assuming mechanical efficiency of 75% and brake mean effective pressure of 5 bar, find the diameter and stroke of the engine.

tion Given:

Number of cylinders (n) = 6, Indicative power, IP = 90 kW, Speed, N = 2500 rpm

$$\text{Number of cycles, } N_c = \frac{2500}{2} = 1250 \text{ cycles/min}$$

$$\text{Stroke to bore ratio} = 1.4:1 = \frac{L}{D}, \text{ Mechanical efficiency, } \eta_{\text{mech}} = 75\%$$

Brake mean effective pressure, $P_{\text{meb}} = 5 \text{ bar} = 5 \times 100 \text{ kN/m}^2$

$$\text{Brake power (BP)} = \frac{P_{\text{meb}} L A N_c}{60}$$

$$= \frac{500 \times 1.4\, D \left(\frac{\pi}{4} D^2\right) \times 1250}{60}$$

Also $\qquad \eta_{mech}$ = Mechanical efficiency = $\dfrac{\text{BP}}{\text{IP}}$

or $\qquad$ BP = 90 × 0.75 = 67.5 kW

$$\therefore \qquad 67.5 = \frac{500 \times 1.4\, D \times \dfrac{\pi}{4} D^2 \times 1250}{60} = 11447.92\, D^3$$

or $\qquad D^3 = 0.005896 \text{ m}^3$

or $\qquad D = 0.180658$ m

or $\qquad D = 180.6$ mm = diameter **Ans.**

and $\qquad L$ = Length of stroke = 252.9 mm **Ans.**

EXAMPLE 8.9 A trial on a single cylinder four-stroke petrol engine which is having 250 mm bore and 500 mm stroke gave the following data: Duration of trial = 1 h, fuel used = 7 l, having specific gravity of 0.8 and CV = 40 MJ/kg, mean effective pressure of engine = 7.25 bar, pump pressure = 0.25 bar, engine revolution = 12000, brake load = 100 kg on the drum of 1.8 m, rope diameter = 4 cm, cooling water circulated = 500 l, temperature rise = 40°C and specific heat = 4.18 kJ/kg·K. Calculate the mechanical efficiency and unaccounted losses.

Solution Given:

$D = 250$ mm, $L = 500$ mm, $W_s = 7$ l/h, $\rho = 0.8$

CV = 40 MJ/kg = 40000 kJ/kg, $P_m = 7.25$ bar

P_m (Pump) = 0.25 bar, $N = 12000$ rpm

Brake load = 100 kg, Drum dia. = 1.8 m, Rope dia. = 4 cm

$W_w = 500$ l/h, Rise in temperature = 40°C, $C_{pw} = 4.18$ kJ/kg·K

Effective pressure = (7.25 – 0.25) bar

$$\text{IP} = \frac{P_m L A N_c}{60}$$

$$\text{IP} = \frac{(7.25 - 0.25) \times 10^2 \times \frac{500}{1000}\left(\frac{250}{1000}\right)^2 \times \frac{\pi}{4} \times \frac{12000}{60 \times 2}}{60} = 28.62 \text{ kW}$$

Here $P_{mei} = (7.25 - 0.25)$ bar

Heat supplied = $7 \times 0.8 \times 40 \times 10^3 = 224000$ kJ/h

$$BP = 2\pi NT = 2\pi \times \frac{12000}{3600} \times (100 \times 9.8) \times \frac{(1.8 + 0.04)}{2} = 18873 \text{ W}$$

$$\therefore \quad \eta_m = \frac{18873 \times 10^{-3}}{28.62} = 0.6594$$

Mechanical efficiency of engine = 65.94% **Ans.**

Heat supplied by fuel = $7 \times 0.8 \times 40000 = 224000$ kJ/h

Heat equivalent to BP = $18.873 \times 60 \times 60$ kJ/h = 67942 kJ/h

Heat lost in cooling water = $500 \times 4.18 \times 40$ kJ/h = 83600 kJ/h

$\therefore$ Unaccounted losses = $224000 - (67942 + 83600)$ kJ/h

= 72458 kJ/h **Ans.**

EXAMPLE 8.16 A four-cylinder diesel engine of a truck has 0.1 m diameter and 0.15 m stroke. The piston speed is 10 m/s and power developed is 20 kW/l of cylinder volume. If the brake thermal efficiency is 40%, the calorific value of fuel is 40 MJ/kg, and the specific gravity of fuel is 0.9, calculate (i) rpm, (ii) brake power, and (iii) fuel requirements in litres.

Solution Given:

Number of cylinders, $n = 4$, Diameter $= D = 0.1$ m, Stroke, $L = 0.15$ m
Piston speed (S) = 10 m/s, Engine power = 20 kW/l
Brake thermal efficiency (η_{bth}) = 0.4, CV = 40 MJ/kg, $\rho = 0.9$

(i) $$\text{Piston speed } (S) = \frac{2LN}{60} = 10,\ N = \frac{10 \times 60}{2 \times 0.15} = 2000 \text{ rpm} \quad \textbf{Ans.}$$

(ii) $$\text{Stroke volume of cylinder} = \frac{\pi}{4} D^2 \times L = \frac{\pi}{4}(0.1)^2 \times (0.15) \times 1000 \text{ l/cylinder}$$

$$= 1.178 \text{ l/cylinder}$$

$$\therefore \quad \text{Total volume} = 4 \times 1.178 = 4.71 \text{ l}$$

$$\text{Brake power of the engine} = 20 \times 4.71 = 94.2 \text{ kW} \quad \textbf{Ans.}$$

(iii) Since $$\eta_{bth} = \frac{\text{BP}}{\text{Fuel consumed/s} \times \text{CV}}$$

or $$0.4 = \frac{94.2}{m_f \times 40{,}000}$$

or $$m_f = 0.005887 \text{ kg/s}$$

or $$m_f = 21.19 \text{ kg/h} = \frac{21.19}{0.9} \text{ l/h} = 23.55 \text{ l/h} \quad \textbf{Ans.}$$

Example 3.26. *A four-cylinder petrol engine has an output of 51.5 kW BP at 2000 rpm. A Morse test was carried out and the brake torque readings were 176.3, 169.5, 166.8 and 173.6 Nm respectively. For normal running at this speed specific fuel consumption is 0.37 kg/bkWh. The LCV of the fuel is 43900 kJ/kg. Calculate the mechanical efficiency and the brake thermal efficiency of the engine.*

Solution.

BP developed when cylinder No. 1 is rendered inoperative

$$= \frac{2\pi N T}{60000} = \frac{2\pi \times 2000 \times 176.3}{60000} = 36.9 \text{ kW}.$$

BP developed when cylinder No. 2 is rendered inoperative

$$= \frac{2\pi \times 2000 \times 169.5}{60000} = 35.5 \text{ kW}.$$

BP developed when cylinder No. 3 is rendered inoperative

$$= \frac{2\pi \times 2000 \times 166.8}{60000} = 34.9 \text{ kW}.$$

BP developed when cylinder No. 4 is rendered inoperative

$$= \frac{2\pi \times 2000 \times 173.6}{6000} = 36.5 \text{ kW}.$$

Therefore, *IP* developed in cylinder No. 1 $= 51.5 - 36.9 = 14.6$ kW.

IP developed in cylinder No. 2 $= 51.5 - 35.5 = 16.0$ kW.

IP developed in cylinder No. 3 $= 51.5 - 34.9 = 16.6$ kW.

IP developed in cylinder No. 4 $= 51.5 - 36.5 = 15.0$ kW.

Hence, *IP* developed by the engine $= 14.6 + 16.0 + + 16.6 + 15.0 = 62.2$kW.

Mechanical efficiency, $\eta_m = \frac{BP}{IP} = \frac{51.5}{62.2} \times 100\% = 82.8\%$. **Ans.**

Brake thermal efficiency, $\eta_b = \frac{60 \times 62.2}{0.37 \times 43900} \times 100\% = 23\%$. **Ans.**

Example 3.23. *An eight-cylinder automobile engine of 85.7 mm bore and 82.5 mm stroke a compression ratio of 7 is tested at 4000 rpm on a dynamometer, which has a 0.5335 m During a 10 minutes test at a dynamometer scale beam reading of 400 N, 4.55 kg of gasoline which the heating value is 46,000 kJ / kg are burnt, and air at 294 K and 10×10^4 N/m^2 is plied to the carburettor at the rate of 5.44 kg per min. Find (a) the BP delivered, (b) the BMEP the BSFC, (d) the specific air consumption, (e) the brake thermal efficiency, (f) the volumetric ciency, (g) the air-fuel ratio.*

Solution.

(a) $$BP = \frac{2\pi NT}{60000} = \frac{2\pi \times 4000 \times 400 \times 0.5335}{60000} = 89.34 \text{ kW.}$$ **Ans.**

(b) $$BP = \frac{8\, p_b\, L\, A\, (N/2)}{60000}$$

$$BMEP,\ P_b = \frac{BP \times 60000}{4\, L\, AN} = \frac{89.34 \times 60000}{4 \times 0.0825 \times [\{\pi(85.7)^2\}/(4 \times 10^6)] \times 4000} = 704.36 \text{ kPa.}$$ **Ans.**

(c) Fuel consumed in one minute, $w_f = 0.455$ kg.

Therefore, $$BSFC = \frac{w_f \times 60}{BP} = \frac{0.455 \times 60}{89.34} = 0.306 \text{ kg/bkWh.}$$ **Ans.**

(*d*) Air consumption in one minute, $w_a = 5.44$ kg.

Therefore, brake specific air consumption,

$$BSAC = \frac{w_f \times 60}{BP} = \frac{5.44 \times 60}{89.34} = 3.65 \text{ kg/bkWh.} \quad \textbf{Ans.}$$

(*e*) Brake thermal efficiency, $\eta_b = \dfrac{BP \times 60}{w_f HV} = \dfrac{89.34 \times 60}{0.455 \times 46000} = 25.6\%.$ **Ans.**

(*f*) Piston displacement $= (\pi/4)\,(0.0857)^2\,(0.0825) = 4.76 \times 10^{-4}$ m^3/cycle.

At 4000 rpm and for four-stroke, eight-cylinder engine,

$$\text{Piston displacement} = \frac{476}{10^2} \times \frac{4000}{2} \times 8 \text{ m}^3\text{/min} = 7.62 \text{ m}^3\text{/min.}$$

$$\text{Volume of air used at intake conditions} = \frac{w_a RT}{p} = \frac{5.44 \times 287.1 \times 294}{10 \times 10^4}$$

$$= 4.56 \text{ m}^3\text{/min.}$$

$$\text{Volumetric efficiency, } \eta_v = \frac{4.56}{7.62} \times 100\% = 60\%. \quad \textbf{Ans.}$$

(*g*) Air: Fuel $= 5.45 : 0.455$ or $A/F = 11.96$. **Ans.**

Example 3.27. *A 4-cylinder, 4-stroke cycle engine in a jeep is running at 2000 rpm and uses 13.15 kg fuel per hour. Each cylinder has a displacement volume of 655.50 ml and the engine draws air through a nozzle. The flow rate Q_a (in cu. metre / min.) through the nozzle is given by $Q_a = 0.231\ (h_a)^{1/2}$ where h_a is the pressure difference in meters of air across the nozzle. If average density of air used is 1.2 kg/m^3 and the water manometer across the nozzle showed a depression of 127 mm, calculate (a) the weight of air drawn in kg / min (b) volumetric efficiency taking air into account and (c) the air-fuel ratio.*

Solution.

$$127 \text{ mm of water } = 127 \times \frac{\text{Density of water}}{\text{Density of air}} \text{ mm of air } = 127 \times \frac{\rho_w}{\rho_a} \text{ mm of air}$$

$$= 127 \times \frac{1000}{1.2} = 10{,}5900 \text{ mm of air} = 105.9 \text{ m of air.}$$

$$Q_a = 0.231\sqrt{105.9} = 2.37 \text{ cu.m/min.}$$

(*a*) Weight of air drawn in, $w_a = 2.37 \times \rho_a = 2.37 \times 1.2 = 2.84$ kg/min. **Ans.**

(*b*) volume of air drawn in per cylinder per cycle $= 2.37 \times \left(\frac{2}{N}\right)\frac{1}{4} = 2.37 \times \frac{2}{2000} \times \frac{1}{4}$

$$= 0.5925 \times 10^{-3} \text{ m}^3.$$

Therefore, volumetric efficiency (taking air into account) $= \frac{592.5}{655.5} \times 100\% = 90.4\%$. **Ans.**

(c) $A : F = w_a : w_f = 2.84 : \left(\frac{13.15}{60}\right) = 13{:}1$. **Ans.**

Example 3.28. *In a trial on 4-cylinder, 4-stroke, petrol engine of 101.6 mm bore, and 127 mm stroke, the net dynamometer load was 183 N at a radius of 508 mm when the speed was 2500 rpm. At this speed and throttle opening the engine required 4.6 kW to motor it with ignition switched off.*

(i) *Calculate the mechanical efficiency and the indicated mean effective pressure.*

(ii) *During a 3 minute run at this speed and power, the engine used 0.598 kg of petrol of heating value 45310 kJ / kg and 22.68 of cooling water with a temperature rise of 55.5 K.*

Draw a heat balance chart of the test in kJ / min.

Solution.

(i)
$$BP = \frac{2\pi NT}{60000} = \frac{2\pi \times 2500 \times 183 \times 0.508}{60000} = 24.3 \text{ kW.}$$

$$IP = BP + FP = 24.3 + 4.6 = 28.9 \text{ kW.}$$

$$\text{Mechanical efficiency, } \eta_m = \frac{BP}{IP} = \frac{24.3}{28.9} \times 100\% = 84\%. \textbf{ Ans.}$$

$$IP = \frac{4\, p_i\, L\, A\, (N/2)}{60000}.$$

$$IMEP, p_i = \frac{60000 \times IP}{2\, L\, A\, N} = \frac{60000 \times 28.9}{2 \times 0.127 \times \pi \dfrac{(101.6)^2}{4 \times 10^6} \times 2500}$$

$$= 337 \times 10^3 \text{ Pa. } \textbf{Ans.}$$

Example 3.28. *In a trial on 4-cylinder, 4-stroke, petrol engine of 101.6 mm bore, and 127 mm stroke, the net dynamometer load was 183 N at a radius of 508 mm when the speed was 2500 rpm. At this speed and throttle opening the engine required 4.6 kW to motor it with ignition switched off.*

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$$IP = BP + FP = 24.3 + 4.6 = 28.9 \text{ kW.}$$

Mechanical efficiency, $\eta_m = \frac{BP}{IP} = \frac{24.3}{28.9} \times 100\% = 84\%.$ **Ans.**

$$IP = \frac{4\,p_i\,L\,A\,(N/2)}{60000}.$$

$$IMEP,\, p_i = \frac{60000 \times IP}{2\,L\,A\,N} = \frac{60000 \times 28.9}{2 \times 0.127 \times \pi \frac{(101.6)^2}{4 \times 10^6} \times 2500}$$

$$= 337 \times 10^3 \text{ Pa.}$$ **Ans.**

(ii) Heat suppied/min $= w_f \times HV = \dfrac{0.598}{3} \times 45310 = 9031.8$ kJ.

Heat carried away by cooling water/min

$$= \frac{22.68}{3} \times 55.5 \times 4.18 = 1755.6 \text{ kJ.}$$

Heat converted into work/min

$$= 60 \times BP = 60 \times 24.3 = 1458.0 \text{ kJ.}$$

Heat Balance Chart in kJ/min.

Heat in	*kJ*	*Heat out*	*kJ*	*%*
Supplied by fuel	9031.8	As *BP*	1458.0	16.18
		To cooling water	1755.6	19.40
		To exhaust, radiation, etc.	5818.2	64.42
Total	9031.8		9031.8	100.00