Internal Combustion Engines (IC Engines)

A heat engine is a thermal prime mover which converts the heat energy released by the combustion of the fuel that is taking place inside the engine cylinder into mechanical energy, which can then be used to perform useful mechanical work.

Heat engines can be broadly classified into following two categories:

(i) External combustion Engines (EC Engines)

In EC engines, combustion of fuel takes place outside the engine cylinder.
These are mainly used for large electric power generation.
Eg: steam engine, steam turbine, closed cycle gas turbine, etc.,

(ii) Internal combustion Engines (IC Engines)

In IC engines, combustion of fuel take place inside the engine cylinder.
These are mainly used in transport vehicales such as automobiles, locomotives, etc.,
Eg: petrol engine, Diesel engine, Gas engine etc:

Internal combustion Engine (IC Engine)

IC Engine is a heat engine which converts the heat energy released due to the combustion fuel which takes place inside the cylinder into a mechanical work.

Classification of IC Engines:

IC engines are classified according to:

(i) Nature of thermodynamic cycle:

(a) Otto cycle engine

(b) Diesel cycle engine

(c) Dual combustion cycle engine

(ii) Type of fuel used:

(a) Petrol engine

(b) Diesel engine

(c) Gas engine

(d) Bio-fuel engine

(iii) Number of strokes per cycle:

(a) Four stroke engine

(b) Two stroke engine

(iv) Method of ignition:

(a) Spark ignition engine (SI engine)

(b) Compression ignition engine (CI engine)

(v) Number of cylinders:

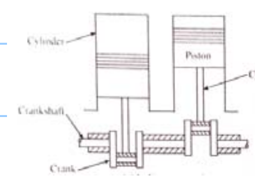
(a) Single cylinder engine

(b) Multi-cylinder engine

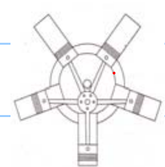
(vi) Arrangement of cylinder

(a) Vertical engine
(b) Horizontal engine
(c) Inline engine
(d) Radial engine
(e) V- engine
(f) opposed type engine

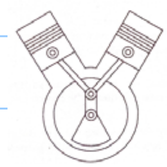
[Below figures are only for your understanding not in the syllabus



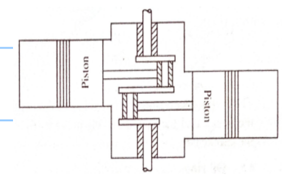
(c) Inline engine



(d) Radial engine



(e) V-engine



(f) opposed type engine]

(vii) Method of cooling:

(a) Air cooled engine
(b) water cooled engine

(viii) Their uses or applications

(a) Stationary engine
(b) Automobile engine
(c) Marine engine
(d) Locomotive engine
(e) Aircraft engine

Parts of IC Engine (only for your understanding not in syllabus)

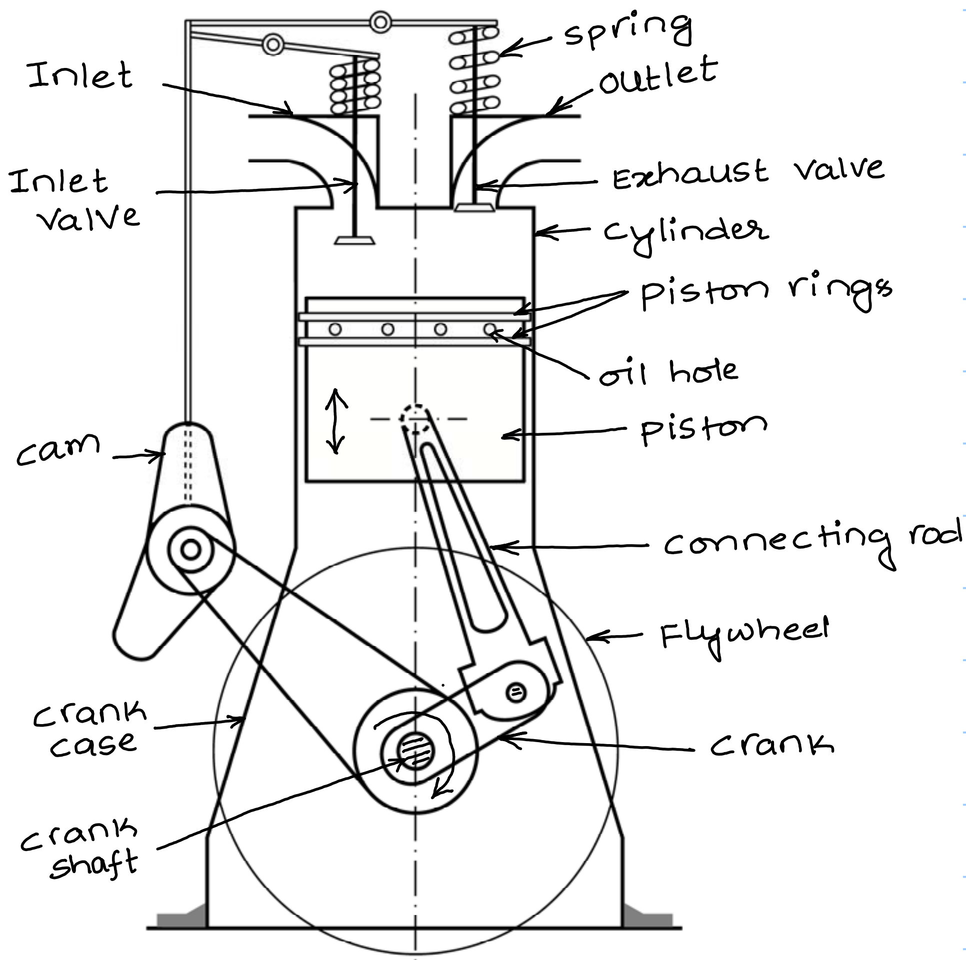


Figure shows the various important parts of an IC engine

(1) Cylinder :

Cylinder is considered as 'Heart of the engine'

It is cylindrical shaped vessel in which combustion of fuel takes place.

The cylinder is usually made of 'Gray cast iron or steel alloys' in order to withstand the high pressure and temperature during combustion.

The piston reciprocates inside the cylinder.

(2) cylinder head

The top end of the cylinder is closed by removable cylinder head. The cylinder head consists of a two valves, Inlet valve and exhaust valve, and spark plug or fuel injector.

The cylinder head is usually made of "cast iron or Alloys of cast iron".

(3) Piston :

The piston is a hollow cylindrical shaped component that fits perfectly inside the cylinder and moves to and fro in the cylinder.

The pistons are usually made of 'Aluminum alloys or low carbon steel'. for lightness and with stand high heat, vibration, and friction.

piston recieve the impulse (force) produced by the combustion of fuel and to transmit the energy to crank shaft through connecting rod.

piston compress the charge during compression stroke

(4) Piston rings

Towards the top of the piston, a few grooves are cut to accomodate metallic rings called piston rings.

The piston rings forms a tight seal between the piston and the cylinder. This prevents the high pressure gases from escaping into the crankcase.

piston rings are usually made of 'cast iron or steel'.

(5) Connecting rod :

The connecting forms a link between the piston and the crankshaft. Its function is to convert the reciprocating motion of the piston into rotary motion of the crank shaft. connecting rods are usually made of 'forged steel or cast steel'.

(6) crank and the crank shaft

The crank is a lever with one of its end connected to the connecting rod, and the other end of the crank is connected to a shaft, is called crank shaft.

The power required for any useful purpose is taken from the crank shaft.

(7) crank case :

It is the lower part of the engine, encloses the crankshaft and serves as a sump for the lubricating oil.

(8) Valves :

The valves are the devices which controls the flow of air/fuel to the cylinder during intake and burnt gases from the cylinder to atmosphere. There are two valves,

Inlet valve, through which fresh charge (air and/or fuel) enters into the cylinder.

Exhaust valve, through which the burnt gases are discharged out of the cylinder.

The valves are actuated by means of springs, cam & lever.

(9) Flywheel:

It is a rotating wheel of heavy mass, mounted on the crank shaft and is used as an energy storing device. The flywheel stores energy received during the power stroke and supplies the same during other strokes.
The flywheel also maintain the uniform rotation of the crankshaft.

Working principle of Four stroke (4-S) Engines

In 4-stroke engines, all the operations of the working cycle are completed in four different strokes of the piston. The four different strokes performed are

(a) suction stroke

(b) compression stroke

(c) Power stroke (expansion stroke)

(d) Exhaust stroke

Each stroke is completed when the crankshaft rotates by 180°. Hence in 4-S engine, the four different strokes are completed through 720° of the crankshaft rotation, ie Two complete rotation of the crankshaft.

Based on the type of fuel used 4-S engines are classified as.

(i) 4-stroke petrol engine and

(ii) 4-stroke Diesel engine

IVO -- Inlet Valve Open
IVC -- Inlet Valve Close
EVO -- Exhaust Valve Open
EVC -- Exhaust Valve Close

(i) 4-stroke Petrol engine :

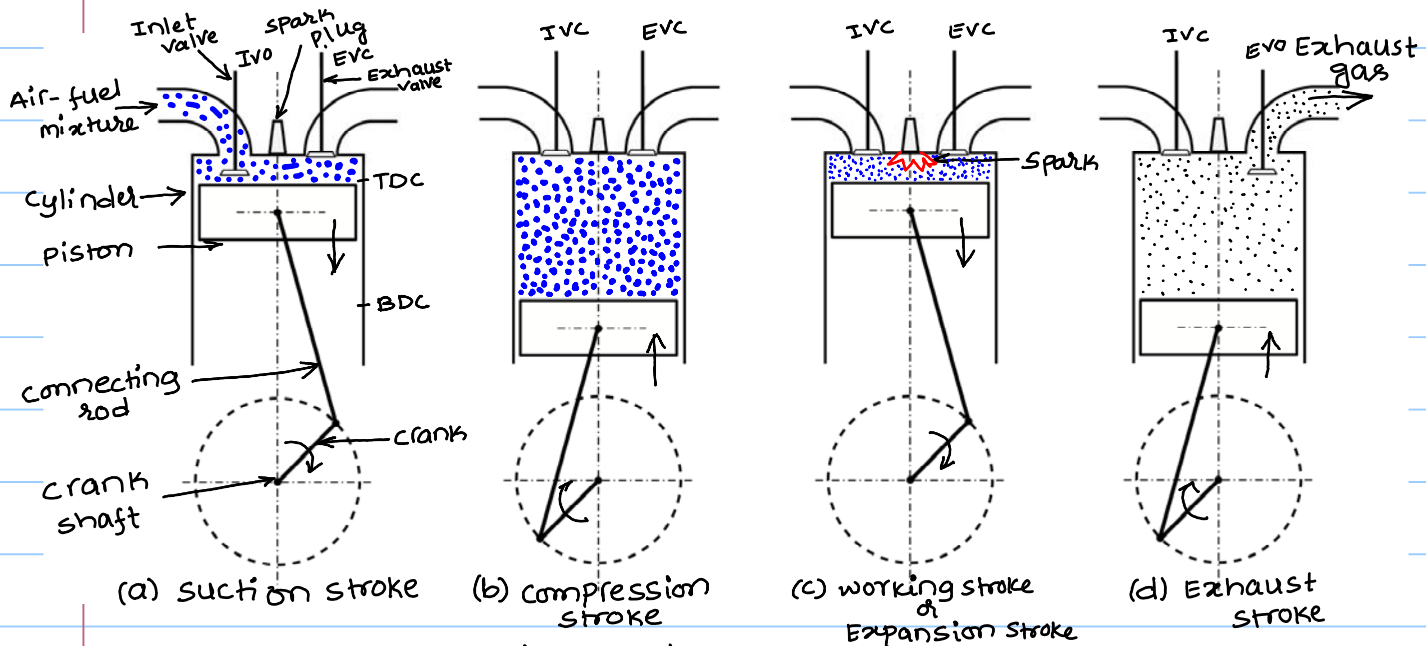
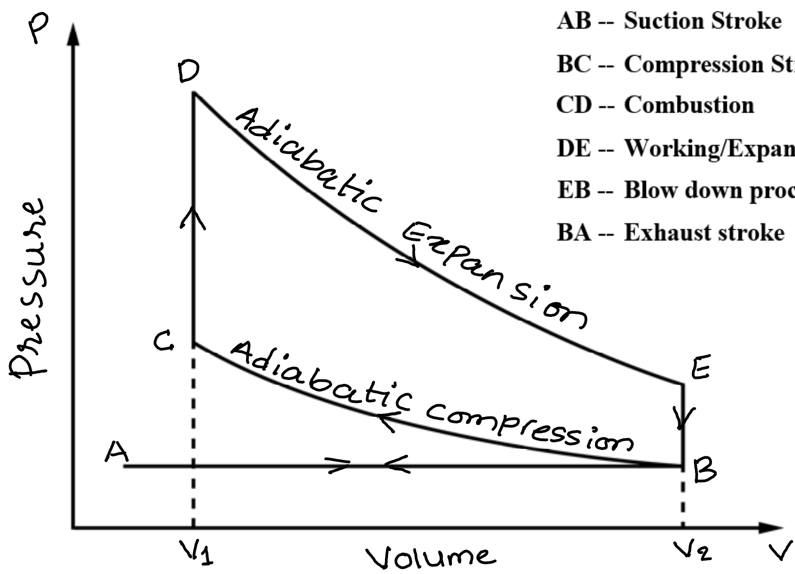


Figure 1



AB -- Suction Stroke
BC -- Compression Stroke
CD -- Combustion
DE -- Working/Expansion stroke
EB -- Blow down process (EVO)
BA -- Exhaust stroke

Figure.2

The working principle of 4-stroke petrol engine is based on 'Otto cycle'. Hence, it is also called as 'Otto cycle engine'

some times it is also called 'Gasoline engine' or 'const volume cycle engine' or 'spark Ignition engine'.

A 4-stroke Petrol engine performs four different strokes namely suction, compression, Power/working/Expansion and Exhaust to complete one cycle.

In 4-stroke Petrol engine, to complete one cycle crank has to rotate 720° or two full rotation

Figure 1 shows the details of the working of each stroke.

In 4-stroke petrol engine, carburetor is used to supply the air and fuel (petrol) mixture (also called as charge)

The detail explanation of working of each stroke is given below.

(a) Suction stroke:

During this stroke, the piston moves from TDC to BDC. The inlet valve opens and exhaust valve will be closed, as shown in Figure 1(a).

As the piston start moving towards downward (BDC), a suction or low pressure is created in the cylinder, and as a result of this, fresh charge (air-fuel mixture) is drawn into the cylinder through the inlet valve.

When the piston reaches the BDC, the suction stroke ends and inlet valve closes. During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which it had stored during the working stroke of the previous cycle.

Figure 2 shows the pressure-volume (P-V) diagram of 4-stroke Petrol engine, line AB in the figure represents the suction stroke.

(b) Compression stroke :

During this stroke, the piston moves from BDC to TDC, both inlet and exhaust valves are closed and it is shown in Fig 1(b) During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which it had stored during the working stroke of previous cycle.

As the piston moves upwards, the air-fuel mixture in the cylinder is compressed adiabatically (compress ratio ranges 7:1 to 11:1) During this the temperature and pressure of the charge increases and this is represented by a line BC in Figure 2.

When the piston reaches the TDC, the spark plug initiates a spark and that ignites the air-fuel mixture and combustion of fuel takes place at constant volume, as a result of this hot gases are relased which increases the pressure. This process is represented by line CD in Figure 2.

Since the combustion (or heat addition) takes place at constant volume, hence 4-stroke petrol engine is called "constant volume cycle engine" or "constant volume heat addition cycle engine".

(iii) working stroke / Power stroke / working stroke :

During this stroke, both inlet and exhaust valves are closed. The high pressure burnt gases expands, due to expansion, the hot gases exerts a large force on the piston and as a result, the piston is pushed from TDC to the BDC as shown in Figure 1(c) and the crankshaft revolves by half rotation. Further, the linear motion of the piston causes the piston to produce mechanical work or power during this stroke. This power is transmitted to the crank shaft through the connecting rod and the crank. As the piston moves downwards, the pressure inside the cylinder decreases gradually due to the adiabatic expansion of the hot gases. This process is represented by a line DE in Figure 2.

When the piston reaches the BDC, the exhaust valve opens and a part of the burnt gases escapes through it. This will suddenly bring down the pressure inside the cylinder to the atmospheric condition at constant volume. This is represented by line DE in Figure 2.

(iv) Exhaust stroke:

During this stroke, the piston moves from BDC to TDC, the inlet valve is closed and exhaust valve opens as shown in Figure 1(d). During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which had stored during the working stroke (or previous stroke). As the piston moves, upward, it forces the remaining burnt gases to the atmosphere through the exhaust valve. This is represented by line BA in Figure 2.

In the next cycle, the piston which is at TDC moves to BDC thereby allowing fresh charge (air-fuel mixture) to enter the cylinder and the process continues

IVO -- Inlet Valve Open
IVC -- Inlet Valve Close
EVO -- Exhaust Valve Open
EVC -- Exhaust Valve Close

(i) 4-stroke diesel engine :

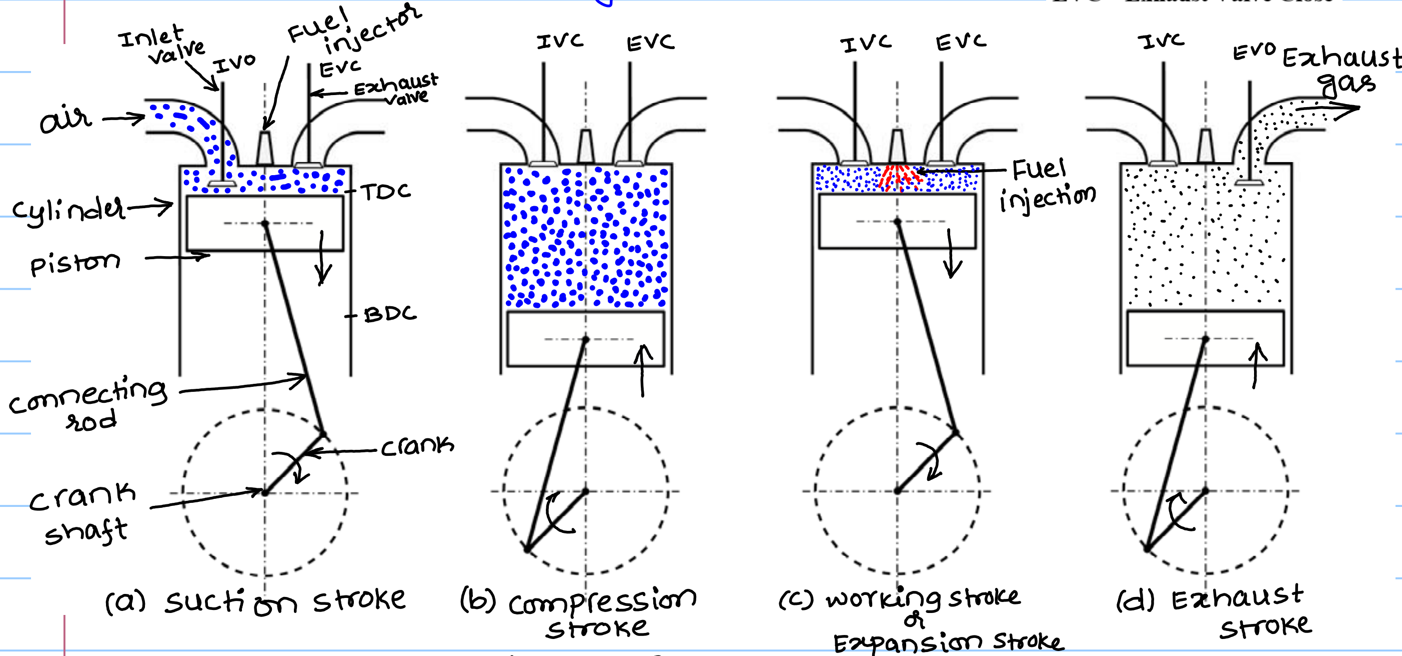


Figure 3

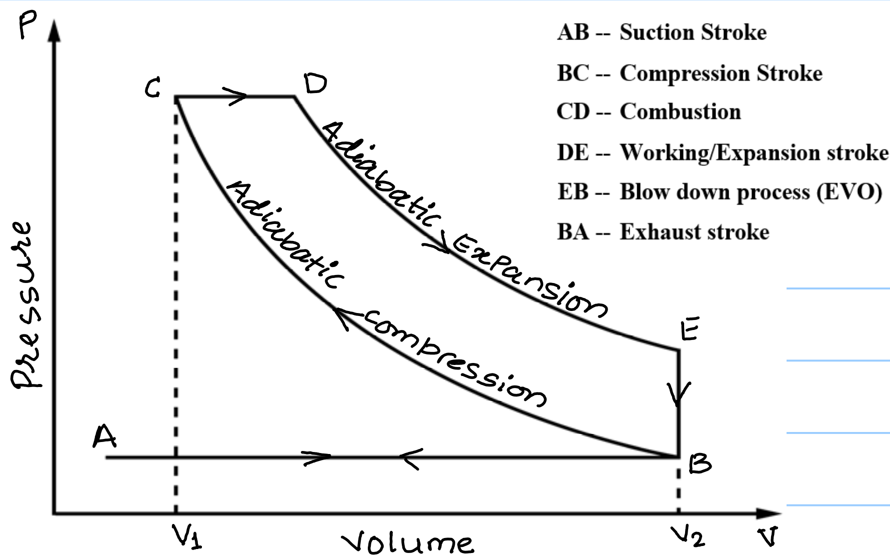


Figure.4

The working principle of 4-stroke diesel engine is based on 'Diesel cycle'. Hence, it is also called as 'Diesel cycle engine'

some times it is also called 'constant pressure cycle engine' or 'compression Ignition Engine'.

A 4-stroke diesel engine performs four different strokes namely suction, compression, power/working/Expansion and Exhaust to complete one cycle.

In 4-stroke diesel engine, to complete one cycle crank has to rotate 720° or two full rotation

Figure 3 shows the details of the working of each stroke.

In 4-stroke diesel engine, fuel injector is used to inject the fuel into the hot compressed air.

The detail explanation of working of each stroke is given below.

(a) Suction stroke:

During this stroke, the piston moves from TDC to BDC. The inlet valve opens and exhaust valve will be closed, as shown in Figure3(a).

As the piston start moving towards downward (BDC), a suction or low pressure is created in the cylinder, and as a result of this, fresh air is drawn into the cylinder through the inlet valve. When the piston reaches the BDC, the suction stroke ends and inlet valve closes. During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which it had stored during the working stroke of the previous cycle.

Figure 4 shows the pressure-volume (P-V) diagram of 4-stroke diesel engine, line AB in the figure represents the suction stroke.

(b) compression stroke:

During this stroke, the piston moves from BDC to TDC, both inlet and exhaust valves are closed and it is shown in Fig 3(b) During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which it had stored during the working stroke of previous cycle.

As the piston moves upwards, the air in the cylinder is compressed adiabatically (compression Ratio ranges from 20:1 to 22:1) During this the temperature and pressure of the air increases and this is represented by a line BC in Figure 4.

When the piston reaches the TDC, the temperature of the compressed air in the cylinder will be greater than the ignition temperature of the diesel, then a metered quantity of diesel is injected into the cylinder in the form of fine sprays or droplet by a fuel injector. Then the fuel ignites as it comes in contact with the hot compressed air and combustion of fuel takes place at constant pressure. As a result of this the volume in the cylinder increases till the fuel supply is cut-off. This process is represented by line CD in Figure 4.

since the combustion (or heat addition) takes place at constant Pressure, hence 4-stroke diesel engine is called "constant pressure cycle engine" or "constant Pressure heat addition cycle engine".

(iii) Working stroke / Power stroke / working stroke :

During this stroke, both inlet and exhaust valves are closed. The high pressure burnt gases expands, due to expansion, the hot gases exerts a large force on the piston and as a result, the piston is pushed from TDC to the BDC as shown in Figure 3(c) and the crankshaft revolves by half rotation.
Further, the linear motion of the piston causes the piston to produce mechanical work or power during this stroke. This power is transmitted to the crank shaft through the connecting rod and the crank. As the piston moves downwards, the pressure inside the cylinder decreases gradually due to the adiabatic expansion of the hot gases. This process is represented by a line DE in Figure 4.
When the piston reaches the BDC, the exhaust valve opens and a part of the burnt gases escapes through it. This will suddenly bring down the pressure inside the cylinder to the atmospheric condition at constant volume. This is represented by line DE in Figure 4.

(iv) Exhaust stroke :

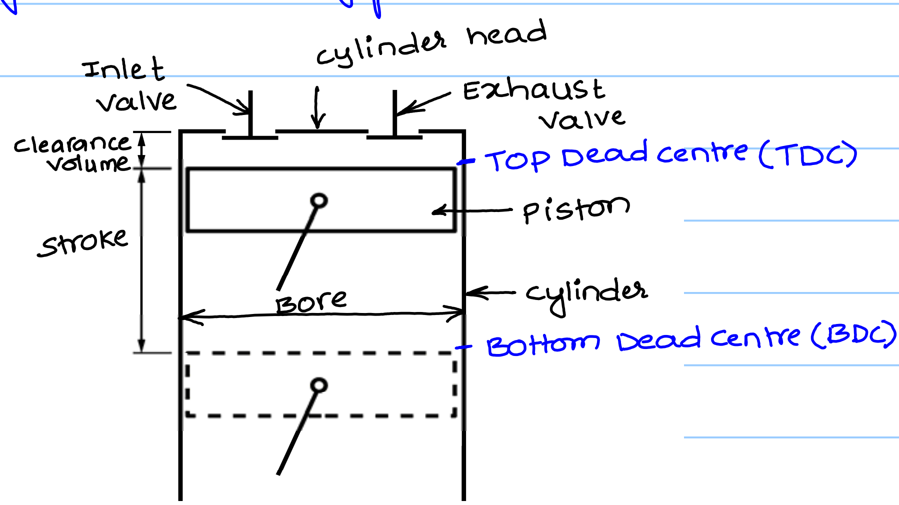
During this stroke, the piston moves from BDC to TDC, the inlet valve is closed and exhaust valve opens as shown in Figure 3(d). During this travel, crankshaft revolves 'half rotation', and the energy required to move the piston is supplied by flywheel which had stored during the working stroke (or previous stroke).

As the piston moves upward, it forces the remaining burnt gases to the atmosphere through the exhaust valve. This is represented by line BA in Figure 4.

In the next cycle, the piston which is at TDC moves to BDC thereby allowing fresh air to enter the cylinder and the process continues

[Note: while explaning 4-S petrol & diesel engine, one should keep in mind that, we look for, you have written, valve position, piston moment ie TDC to BDC or BDC to TDC, crank rotation, and also what is entering into the cylinder and leaving. Moreover how combustion process takes place (spark plug or fuel injector) correctly, Further, representation of process on P-V diagram]

IC Engine terminology



(i) Bore (D): The inside diameter of the cylinder is called 'bore'.

(ii) Top Dead centre (TDC): The extreme position of the piston nearer to the cylinder head is called 'Top Dead centre' or 'cover end' in short it is also called as 'TDC'.

(iii) Bottom Dead centre (BDC): The extreme position of the piston nearer to the crank shaft is called 'Bottom Dead Centre' or 'crank end' in short it is also called as 'BDC'.

(iv) Stroke (L): It is the linear distance travelled by piston from the TDC to BDC.

(v) clearance volume (V_c): The volume of the cylinder above the top of the piston, when the piston is at the TDC is called 'clearance volume'. It is denoted by 'V_c'.

(vi) Swept volume or stroke volume (V_s): The volume swept by the piston as it moves from BDC to TDC or TDC to BDC is called 'swept volume'.

It is denoted by 'V_s' and expressed as shown

V_s = C/s area of the cylinder × stroke or

= C/s area of the Piston × stroke

$$\boxed{V_s = AL = \frac{\pi}{4} D^2 L} \; m/s \Rightarrow$$

It is also called as 'displacement volume'.

(vii) Piston speed (V_p): The average speed of the piston is called 'piston speed'

V_p = Distance travelled by the Piston in one revolution of crank shaft i.e 360° (in meters) × No. of revolution (RPM)

$$\boxed{\therefore V_p = 2LN} \; m/min$$

(viii) Compression ratio (CR): It is the ratio of the total cylinder volume to the clearance volume

$$CR = \frac{\text{Total cylinder volume}}{\text{clearance volume}} = \frac{V_c + V_s}{V_c}$$

** for your information only.

[Most of the modern automobile petrol engine generally have a compression ratio (CR) of 7 : 1 to 11 : 1 and Diesel enigines have a compression ratio between 20 : 1 to 22 : 1]

Simple (performance) calculations in IC Engine

(i) Indicated power (IP)

"The total power developed inside the engine cylinder is called Indicated power. It is denoted by IP, and is expressed in kW (read as kilo watts)."

The IP is given by

$$\boxed{IP = \left(\frac{10}{6}\right) i\, P_m L A N K} \quad kW$$

where, i = no. of cylinders

P_m = mean effective pressure (MEP) in Bars

L = Length of stroke in m (ie meteres)

A = C/s area of the cylinder $= \frac{\pi D^2}{4}$ in m^2

D = dia of cylinder or bore in m.

N = Engine speed or crank shaf rotation in RPM

$K = 1/2$ for 4-stroke engine

(a) Mean Effective pressure (P_m) or MEP

"It is the hypothetical mean or average pressure in the cylinder or acting on the piston during a complete engine cycle.

It is denoted by 'P_m' and expressed in 'Bar or Pa or N/m^2'

$$1\ Pa = 1\ N/m^2$$

$$1\ N/m^2 = 10^{-4}\ N/cm^2$$

$$1\ Bar = 10^5\ N/m^2 \text{ or } 10^5\ Pa$$

$$1\ MPa = 10^6\ N/m^2 \text{ or } 10^6\ Pa \text{ or } 10\ Bar$$

Mean Effective pressure can be of two types

✓(i) Indicated Mean effective pressure (we are intersted in this)

✗(ii) Brake mean effective pressure (No need to worry about this)

The indicated mean effective pressure of an engine is obtained from the indicator diagram.

The indicator diagram is the p-v diagram for one cycle at the applied load.

This diagram is drawn with the help of an 'indicator' fitted on the engine.

The indicator consists a marker and a spring. As the pressure inside the cylinder varies, the spring displaces and marker moves accordingly and the diagram is drawn on a sheet that is placed for the purpose.

∴ The indicated mean effective pressure is given by

$$P_m = \frac{\left(\begin{array}{c}\text{spring value of the spring} \\ \text{used in the indicator (S)} \\ \text{in Bar/m}^2 \text{ or } \underline{\underline{\text{Bar/cm}^2}}\end{array}\right) \times \left(\begin{array}{c}\text{net area of the} \\ \text{indicator diagram (a)} \\ \text{in m}^2 \text{ or } \underline{\underline{\text{cm}^2}}\end{array}\right)}{\text{length of the indicator diagram } (l) \text{ in m or } \underline{\underline{\text{cm}}}}$$

$$\boxed{P_m = \frac{Sa}{l}} \quad \text{in } \underline{\underline{\text{Bar}}}$$

only for your understanding, that how we got the formula of Indicated Power (IP).

$$\begin{array}{c}\text{Work produced by the} \\ \text{piston/stroke or cycle}\end{array} = \left[\begin{array}{c}\text{Mean force acting} \\ \text{on the piston}\end{array}\right] \times \left[\begin{array}{c}\text{piston displacement} \\ \text{in one stroke}\end{array}\right]$$

$$= [\text{mean effective pressure} \times \text{area}] \times L$$

$$= P_m A L \quad (\text{in J or N-m})$$

$$\begin{array}{c}\text{work produced by the} \\ \text{the piston/minute}\end{array} = \left[\begin{array}{c}\text{work produced by the} \\ \text{piston/cycle}\end{array}\right] \times \left[\begin{array}{c}\text{No. of cycle} \\ \text{per minute}\end{array}\right]$$

$$= P_m L A n \quad \left(\text{in J/min or } \frac{\text{N-m}}{\text{min}}\right)$$

where, n = no. of cycle/min

$$\boxed{n = NK}$$

N = speed of the crankshaft in $\underline{\underline{\text{RPM}}}$

$$K = \frac{\text{one comple cycle}}{\text{no. of rotation made by crankshaft}}$$

$\therefore$ $K = \frac{1}{2}$ for 4-stroke engines

$= 1$ for 2-stroke engines ← out of scope

$\therefore$ work produced by the piston / minute $= P_m L A n = P_m L A N K \left(\frac{N\text{-}m}{min}\right)$

work produced by the piston / second $= \frac{P_m L A N K}{60} \left(\frac{N\text{-}m}{s} \text{ or } \frac{J}{s} \text{ or } W\right)$

$= \frac{P_m L A N K}{60 \times 1000}$ (in kW)

In the above formula P_m is Pa or N/m^2.

Generally, P_m is expressed in Bar

$\therefore$ WKT $1 \text{ Bar} = 10^5 \ N/m^2$

$\therefore$ work produced by the piston / second $= \frac{10^5 P_m L A N K}{60000}$ (kW)

$= \left(\frac{10}{6}\right) P_m L A N K$

If no. of cylinder present in the cylinder ar 'i'

$\therefore$ work produced by the piston / second for 'i' cylinders $= \left(\frac{10}{6}\right) i P_m L A N K$

$\therefore$ Indicated power (IP) = work produced by the piston / second for 'i' cylinders

$$\boxed{\therefore IP = \left(\frac{10}{6}\right) i P_m L A N K} \text{ (in kW)}$$

$K = \frac{1}{2}$ for 4-stroke engine

(ii) Brake power (BP):

The net power available at the crankshaft is called Brake power. It is denoted by BP, and expressed in kW, and is given by

$$\boxed{BP = \frac{2\pi N T}{60000}} \quad (\text{in kW})$$

where, N = speed of the engine or speed of the crankshaft in RPM

T = Torque applied in N-m

[Some times, speed of the engine or the crankshaft can be expressed in rad/s, it is known as angular speed represented by 'ω' and is given by

$$\omega = \frac{2\pi N}{60} \ (\text{in rad/s}) = 2\pi N \ (\text{in rad/min})$$

then, $\boxed{BP = \frac{\omega T}{1000}}$ (in kW)]

The torque applied is measured by using

(i) Belt dynamometer or

(ii) Rope brake dynometer.

(i) Belt dynamometer

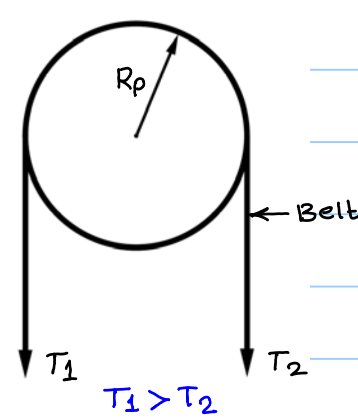
Torque (T) = Force x distance in N-m.

$T = (T_1 - T_2) \times R_p$ in N-m

where, T_1 = Tension in tight side of the belt (N)

T_2 = Tension in slack side of the belt (N)

R_p = Radius of the pulley (m)



(ii) Rope brake dynamometer

Torque = Force × distance

T = effective brake load × effective radius

$T = (W - S) \times R_{eff}$ (N-m)

where,

W = suspended weight (N)

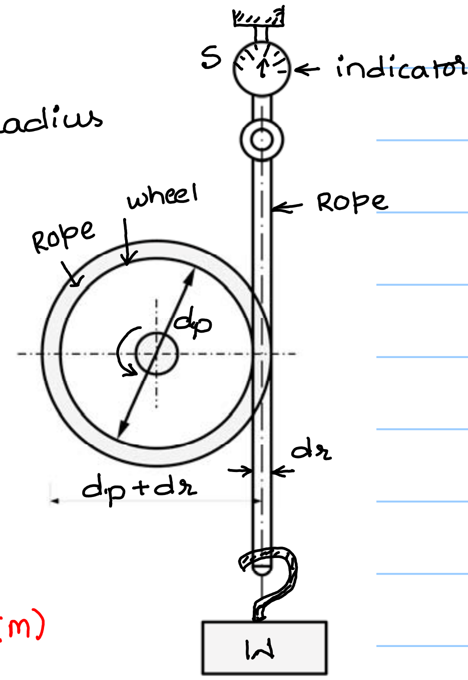
S = Spring balance reading (N)

R_{eff} = Effective radius (m)

$= \dfrac{d_p + d_r}{2}$

d_p = Diameter of the pulley or brake drum (m)

d_r = Diameter of the rope (m)



The power available at the crankshaft is measured by applying the brake and is therefore called Brake power.

[The power developed inside the cylinder is transmitted to the crankshaft through the piston, connecting rod, crank. Hence, a fraction of the indicated power, which is the actual power developed is lost due to friction of these moving parts. So, the net power available at the crankshaft for doing useful work ie the brake power is always less than indicated power.]

(iii) Friction Power (FP) :

The amount of power lost due to friction of the moving parts inside the engine cylinder is called friction power. Friction power is the difference between indicated power and brake power. It is denoted by FP and is expressed in KW, and is given by

$$IP = BP + FP$$

$$\boxed{\therefore FP = IP - BP} \quad \text{(in KW)}$$

(iv) Mechanical efficiency (η_{mech}) :

It is defined as the ratio of brake power to the indicated power, It is denoted by η_{mech} and expressed in % (Percentage), and is given by

$$\boxed{\eta_{mech} = \frac{BP}{IP} \times 100} \quad \%$$

✗ (V) Thermal efficiency (η_{TH})

It is defined as the ratio of power output to the heat supplied by the combustion of fuel. It is denoted by η_{TH}, is expressed in % (Percentage), and given by

$$\eta_{TH} = \frac{\text{Power output}}{\text{heat supplied}} \times 100$$

$$\boxed{\eta_{TH} = \frac{\text{Power output}}{\dot{m}_f \times CV} \times 100} \quad \%$$

where, $\dot{m}_f$ = mass flow rate of the fuel (kg/s)

CV = calorific value of the fuel (kJ/kg)

[Calorific value of fuel is defined as the amount of heat liberated when one kg. of fuel is burnt at standard atmospheric pressure and temperature].

In the above formula, the power output may be indicated power (IP) or brake power (BP).

Hence, the thermal efficiency based on IP is called as Indicated thermal efficiency, and if the thermal efficiency based on BP is called as Brake thermal efficiency.

(a) Indicated thermal efficiency (η_{ITH})

It is defined as the ratio of Indicated power to the heat supplied by the combustion of fuel. It is denoted by η_{ITH}, is expressed in % (Percentage), and given by

$$\eta_{ITH} = \frac{IP\ (kW)}{\dot{m}_f\ (kg/s) \times CV\ (kJ/kg)} \times 100 \quad \%$$

(b) Brake thermal efficiency (η_{BTH})

It is defined as the ratio of Brake power to the heat supplied by the combustion of fuel. It is denoted by η_{BTH}, is expressed in % (Percentage), and given by

$$\eta_{BTH} = \frac{BP\ (kW)}{\dot{m}_f\ (kg/s) \times CV\ (kJ/kg)} \times 100 \quad \%$$

Comparision between Petrol and Diesel Engines

Sl. No	Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
1	Cycle of operation	Works on Otto Cycle or constant volume cycle	Works on Diesel Cycle or constant pressure cycle
2	Fuel used	Petrol/Gasoline	Diesel
3	Admission of charge	Mixture of air and fuel enters the cylinder through carburetor	Only air enters into the cylinder
4	Ignition of fuel	Ignition takes place by means of spark plug	The fuel is ignited when it is sprayed on hot compressed air.
5	Compression ratio	7:1 to 10:1	16:1 to 22:1
6	Power	Power developed is lower due to low compression ratio	Power developed is higher due to high compression ratio
7	Thermal efficiency	Thermal efficiency is low due to lower compression ratio	Thermal efficiency is high due to higher compression ratio
8	Weight	Lighter in weight and also occupies less space	Heavier and also requires more space
9	Running/operating cost	In the current scenario, the initial cost of the petrol engine is less, however the operating cost is high due its higher price.	In the current scenario, the initial cost of the Diesel engine is more, however the operating cost is less due its lesser price.
10	Uses	Used in light duty vehicles such as cars, motorcycles, etc.	Used in heavy duty vehicles like trucks, buses, etc.

Applications of IC Engines

1. IC engines are used in road vehicles like scooters, motor cycles, buses etc.
2. It is also used in aircraft.
3. IC engines are commonly used in motor boats
4. Used in small machines, locomotives, and portable engine generators.

Note Title

Worked Examples of IC Engine

1) A 4-stroke diesel engine has a piston diameter of 250 mm and stroke 400 mm. The mean effective pressure is 4 Bar and the crank speed is 500 rpm. The diameter of the brake drum is 1000 mm and the effective brake load is 400 N. Find indicated power, brake power, frictional power, and mechanical efficiency.

Given

4-s diesel engine, $i = 1$

$K = \frac{1}{2}$, $D = 250\,mm = 0.25\,m$, $L = 400\,mm = 0.4\,m$, $P_m = 4\,Bar$

$N = 500\,rpm$, $d_{bd} = 1000\,mm = 1\,m$, $(W-S) = 400\,N$,

To find

$IP = ?$ $BP = ?$ $FP = ?$ $\eta_{mech} = ?$

Sol^n

(i) $IP = \left(\frac{10}{6}\right) i\, P_m L A N K \quad (KW)$

$$= \left(\frac{10}{6}\right) \times 1 \times 4(Bar) \times 0.4\,(m) \times \frac{\pi}{4}(0.25)^2 (m^2) \times 500 (rpm) \times \frac{1}{2}$$

$$\boxed{IP = 32.72\ KW}$$

(ii) $BP = \frac{2\pi N T}{60000} \quad (KW)$

To find out the brake power, brak drum dynamometer is used to apply the brake and the torque developed during this loading condition is given by

$$T = \text{Net effective load} \times \text{Effective radius}$$

$$= (W-S) \times R_{eff} = (W-S)\frac{(d_{bd} + d_r)}{2}$$

rope diameter not given means it is neglected in this case

$$T = (W-S)\frac{d_{bd}}{2} \quad (N\text{-}m)$$

$$\therefore T = 400(N) \times \frac{1}{2}(m)$$

$$\boxed{\therefore T = 200\ N\text{-}m}$$

$$\therefore BP = \frac{2\pi \times 500\,(rpm) \times 200\,(N\text{-}m)}{60000}$$

$$\boxed{\therefore BP = 10.47\ KW}$$

(iii) $FP = IP - BP \quad (KW)$

$$= 32.72 - 10.47$$

$$\boxed{\therefore FP = 22.25\ KW}$$

(iv) $\eta_{mech} = \frac{BP}{IP} \times 100$

$$= \frac{10.47}{32.72} \times 100$$

$$\boxed{\therefore \eta_{mech} \approx 32\%}$$

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(2) A single cylinder 4-stroke engine runs at 1000 rpm and has a bore of 115 mm and a stroke of 140 mm. The brake load is 60 N at 600 mm radius and the mechanical efficiency is 80%. Calculate brake power and mean effective pressure.

Given

$i = 1$, $K = \frac{1}{2}$, $N = 1000\ rpm$, $D = 115\ mm = 0.115\ m$,

$L = 140\ mm = 0.140\ m$, $(W - S) = 60\ N$, $R_{eff} = 600\ mm = 0.6\ m$

$\eta_{mech} = 80\%$

To find

$BP = ?$ $\quad P_m = ?$

(i) $BP = \frac{2\pi NT}{60000} \quad (KW)$

$$T = (W - S)\,R_{eff} = 60 \times 0.6$$

$$\boxed{\therefore T = 36\ N\text{-}m}$$

$$\therefore BP = \frac{2\pi \times 1000 \times 36}{60000}$$

$$\boxed{BP = 3.77\ KW}$$

(ii) we know that

$$IP = \left(\frac{10}{6}\right) i\, P_m L A N K \quad (KW)$$

WKT $\quad \eta_{mech} = \frac{B.P}{IP} \times 100 \Rightarrow IP = \frac{B.P}{\eta_{mech}} \times 100$

$$\therefore IP = \frac{3.77}{80} \times 100$$

$$\boxed{\therefore IP = 4.71 \text{ KW}}$$

$$4.71 = \left(\frac{10}{6}\right) \times 1 \times P_m \times 0.140 \times \frac{\pi}{4}(0.115)^2 \times 1000 \times \frac{1}{2}$$

$$\boxed{\therefore P_m = 3.89 \text{ Bar}}$$

(3) A 4-stroke IC engine running at 450 rpm has bore diameter 100 mm and stroke length 120 mm. The details of the indicator diagram are as follows.

Area of the indicator diagram = 4 cm^2

Length of the indicator diagram = 6.5 cm and

The spring value of the spring used is 10 Bar/cm. calculate the indicated power

Given

$i = 1$, $K = \frac{1}{2}$, $N = 450$ rpm, $D = 100mm = 0.1m$, $L = 120mm = 0.12m$,

$a = 4 cm^2$, $l = 6.5cm$, $S = 10$ Bar/cm

To find

$IP = ?$

Soln

$$IP = \left(\frac{10}{6}\right) i\, P_m L A N K \quad (KW)$$

But $\quad P_m = \frac{Sa}{l} = \frac{10(\text{Bar}/\cancel{cm}) \times 4(cm^{\cancel{2}})}{6.5(\cancel{cm})}$

$$\boxed{\therefore P_m \simeq 6.15 \text{ Bar}}$$

$$\therefore IP = \left(\frac{10}{6}\right) \times 1 \times 6.15 \times 0.12 \times \frac{\pi}{4}(0.1)^2 \times 450 \times \frac{1}{2}$$

$$\boxed{\therefore IP = 2.17 \text{ KW}}$$

(4) A 4-cylinder 4-stroke petrol engine develops 26 kW brake power at 2200 rpm. The mean effective pressure is 7 Bar and mechanical efficiency is 87%. Determine the bore diameter and stroke of the engine if stroke length is 1.5 times the bore.

Given

$i = 4, \quad K = 1/2, \quad BP = 26 kW, \quad N = 2200 rpm, \quad P_m = 7 Bar,$

$\eta_{mech} = 87\%, \quad L = 1.5D$

To find

$D = ? \quad L = ?$

Sol^n

$$\eta_{mech} = \frac{BP}{IP} \times 100 \Rightarrow IP = \frac{26}{0.87}$$

$$\boxed{\therefore IP = 29.88 kW}$$

WKT

$$IP = \left(\frac{10}{6}\right) i P_m L A N K$$

$$29.88 = \left(\frac{10}{6}\right) \times 4 \times 7 \times 1.5D \times \frac{\pi}{4} D^2 \times 2200 \times \frac{1}{2}$$

$$D^3 = 4.94 \times 10^{-4} m^3$$

$$\boxed{\therefore D = 0.07905 m \text{ or } 79.05 mm}$$

$$L = 1.5D = 1.5 \times 0.07905$$

$$\boxed{\therefore L = 0.11857 m = 118.57 mm}$$

(5) A 4-stroke IC engine has a piston diameter of 150 mm and the average piston speed is 3.5 m/s. If the MEP is 0.786 MPa, find the IP of the engine.

Given

$i = 1, \quad K = \frac{1}{2}, \quad D = 0.15 m, \quad V_p = 3.5 m/s, \quad P_m = 0.786 MPa = 7.86 Bar$

To find

$IP = ?$

Sol^n

$$IP = \left(\frac{10}{6}\right) i P_m L A N K$$

BUT $V_p = \frac{2LN}{60} (m/s) \Rightarrow LN = \frac{60 \times V_p}{2} = 105 m/min$

$$\therefore IP = \left(\frac{10}{6}\right) \times 1 \times 7.86 \times 105 \times \frac{\pi}{4} \times 0.15^2 \times \frac{1}{2}$$

$$\boxed{\therefore IP = 12.15 kW}$$

(6) Calculate the brake power output of a single cylinder 4-stroke engine given: Diameter of brake wheel = 600 mm, Brake rope diameter = 30 mm;

Given

$i = 1$, $K = \frac{1}{2}$, $d_b = 0.6m$, $d_r = 0.03\ m$, $W = 24kg$, $S = 4kg$

$N = 450\ rpm.$

To find

$BP = ?$

Sol^n

WKT $BP = \frac{2\pi N T}{60000}\ (kW)$

$T = (W - S) R_{eff}$

$R_{eff} = \frac{d_d + d_r}{2} = \frac{0.6 + 0.03}{2} = 0.315m$

as we can see W & S are given in kgs, we have convert those values into 'N'

$W - S = (24 - 4) = 20\ kg$

$\therefore W - S = 20 \times 9.81 = 196.2\ N$

$\therefore T = (W - S) R_{eff} = 196.2 \times 0.315$

$\boxed{\therefore T = 61.803\ N\text{-}m}$

$\therefore BP = \frac{2\pi \times 450 \times 61.803}{60000}$

$\therefore \boxed{BP = 2.91\ kW}$

(7) The following details are the test results of a single cylinder, 4-stroke IC engine. IP = 26 kW; BP = 22 kW, Engine speed = 400 rpm; Fuel/BP hour = 0.33 kg, Calorific Value = 44300 kJ/kg. Determine (a) Mechanical efficiency, (b) Indicated thermal

Given

$i = 1$, $K = 1/2$, $IP = 26kW$, $BP = 22kW$, $N = 400\ rpm$

$\frac{Fuel}{BP\ hour} = 0.33kg$, $CV = 44300\ kJ/kg$

To find

(i) η_{mech} (ii) η_{ITH} (iii) η_{BTH}

Sol^n

(i) $\eta_{mech} = \frac{BP}{IP} \times 100 = \frac{22}{26} \times 100$

$\therefore \boxed{\eta_{mech} = 84.61\,\%}$

(ii) $\eta_{ITH} = \frac{IP}{\dot{m}_f \times CV} \times 100$

w.k.t $\frac{\text{Fuel}}{BP \times \text{hour}} = 0.33\,kg \Rightarrow \frac{\text{Fuel}}{\text{hour}} = 0.33 \times BP = \dot{m}_f$

$\therefore \dot{m}_f = 0.33 \times 22 = 7.26\ kg/hr$

$\dot{m}_f = \frac{7.26}{3600}\ kg/s$

$\therefore \boxed{\dot{m}_f = 2.017 \times 10^{-3}\ kg/s}$

$\therefore \eta_{ITH} = \frac{26}{2.017 \times 10^{-3} \times 44300} \times 100$

$\boxed{\eta_{ITH} = 29.1\,\%}$

(iii) $\eta_{IBT} = \frac{BP}{\dot{m}_f \times CV} \times 100$

$= \frac{22}{2.017 \times 10^{-3} \times 44300} \times 100$

$\therefore \boxed{\eta_{IBT} = 24.62\,\%}$

(8) The following observations were recorded during a test on a 4-stroke IC engine Bore = 25 cm; Stroke = 40 cm; Crank speed = 250 rpm; Net load on brake drum = 70 kg; Diameter of brake drum = 2 m; Indicated MEP = 6 Bar; Fuel consumed = 0.1 m^3/min; Specific Gravity of fuel = 0.78; Calorific Value of the fuel = 43900 kJ/kg. Determine: BP, IP, FP, Mechanical Efficiency, indicated thermal efficiency, Brake

Given

$i = 1$, $k = \frac{1}{2}$, $D = 0.25 m$, $L = 0.4 m$, $N = 250$ rpm, $(W-S) = 70$ kg

$d_b = 2 m$, $P_m = 6$ Bar, Volume flow rate $= 0.1\ m^3/min$, $SG = 0.78$

$CV = 43900$ kJ/kg

To find

(i) BP, (ii) IP, (iii) FP, (iv) η_{mech} (v) η_{ITH} (vi) η_{BTH}

Sol^n

(i) $BP = \frac{2\pi N T}{60000}$

$T = (W-S) R_{eff}$

$R_{eff} = \frac{d_b}{2} = \frac{2}{2} = 1 m$

$(W-S) = 70 \times 9.81 = 686.7\ N$

$\boxed{T = 686.7\ N\text{-}m}$

$\therefore BP = \frac{2\pi \times 250 \times 686.7}{60000}$

$\boxed{BP = 17.98\ kW}$

(ii) $IP = \left(\frac{10}{6}\right) i P_m L A N K$

$= \left(\frac{10}{6}\right) \times 1 \times 6 \times 0.4 \times \frac{\pi}{4} \times (0.25)^2 \times 250 \times \frac{1}{2}$

$\therefore \boxed{IP = 24.54\ kW}$

(iii) $FP = IP - BP = 24.54 - 17.98$

$\therefore \boxed{FP = 6.56\ kW}$

(iv) $\eta_{mech} = \frac{BP}{IP} \times 100 = \frac{17.98}{24.54} \times 100$

$\therefore \boxed{\eta_{mech} = 73.32\%}$

(v) $\eta_{ITH} = \frac{IP}{\dot{m}_f \times CV} \times 100$

But in the given quantity, volume flow rate (m^3/min) is given in place of mass flow rate (kg/s)

$\therefore$ WKT $\dot{m}_f (kg/s) = \dot{V}_f (m^3/s) \times \rho_{fuel} (kg/m^3)$

WKT $S.G = \frac{\rho_{fuel}}{\rho_{std\ fluid}}$

standar fluid here is air and $\rho_{air} = 1\ kg/m^3$

$\therefore \rho_{fuel} = \rho_{air} \times SG = 1 \times 0.78$

$\therefore \boxed{\rho_{fuel} = 0.78\ kg/m^3}$

$\therefore \dot{m}_f = \left(\frac{0.1}{60}\right) \times 0.78$

$\therefore \boxed{\dot{m}_f = 1.3 \times 10^{-3}\ kg/s}$

$\therefore \eta_{ITH} = \frac{IP}{\dot{m}_f \times CV} \times 100 = \frac{24.54}{1.3 \times 10^{-3} \times 43900} \times 100$

$\therefore \boxed{\eta_{ITH} = 43\%}$

(vi) $\eta_{BTH} = \frac{BP}{\dot{m}_f \times CV} = \frac{17.98}{1.3 \times 10^{-3} \times 43900}$

$\therefore \boxed{\eta_{BTH} = 31.50\%}$

(9) A 4-stroke diesel engine develops 5 kW. Its indicated thermal efficiency is 30% and mechanical efficiency 57%. Estimate (a) IP and (b) brake thermal efficiency. Also find the fuel consumption of engine in (c) kg/hr, and (d) liter/hr. Take the density of fuel 0.87 kg/m³ and calorific value of the fuel = 42000 kJ/kg.

Given

$i = 1$, $K = 1/2$, $BP = 5\,KW$ (one has to BP, if it is given as engine develops the power), $\eta_{ITH} = 30\%$, $\eta_{mech} = 57\%$, $\rho_{fuel} = 0.87\,kg/m^3$

$CV = 42000\,KJ/Kg$.

To find

(i) IP (ii) η_{BTH} (iii) $\dot{m}_f$ in kg/hr (iv) $\dot{V}_f$ in $\frac{\text{liter}}{\text{hr}}$

Sol^n

(i) $$\eta_{mech} = \frac{BP}{IP} \times 100 \Rightarrow IP = \frac{BP}{\eta_{mech}} \times 100 = \frac{5}{0.57}$$

$$\therefore \boxed{IP = 8.77\,KW}$$

(ii) $$\eta_{BTH} = \frac{BP}{\dot{m}_f \times CV} \times 100 = \left(\frac{IP}{\dot{m}_f \times CV} \times 100\right) \times \left(\frac{BP}{IP} \times 100\right) \times \frac{1}{100}$$

$$\therefore \eta_{BTH} = \eta_{ITH} \times \eta_{mech} \times \frac{1}{100} \quad \%$$

$$= (30 \times 57) \times \frac{1}{100}$$

$$\therefore \boxed{\eta_{BTH} = 17.1\,\%}$$

(iii) $$\eta_{ITH} = \frac{IP}{\dot{m}_f \times CV} \times 100 \Rightarrow \dot{m}_f = \frac{IP}{\eta_{ITH} \times CV} \times 100$$

$$\therefore \dot{m}_f = \frac{8.77}{30 \times 42000} \times 100$$

$$\therefore \boxed{\dot{m}_f = 6.96 \times 10^{-4}\,kg/s}$$

$$\dot{m}_f = 6.96 \times 10^{-4} \times 3600 \quad (kg/hr)$$

$$\therefore \boxed{\dot{m}_f = 2.506\,kg/hr}$$

(iv) $$\dot{V}_f\,(m^3/hr) = \dot{m}_f\,(kg/hr) / \rho_{fuel}\,(kg/m^3) = \frac{2.506}{0.87}$$

$$\therefore \dot{V}_f = 2.88\,m^3/hr \text{ or } \boxed{\dot{V}_f = 2880.46\,ltr/hr}$$

$\because 1\,m^3 = 1000$ ltrs

(10) A single cylinder 4-stroke IC engine has a swept volume of 6 liters and runs at a rated speed of 300 rpm. At full load, the torque developed was measured with a belt dynamometer whose pulley diameter is 1 m. the tension in the tight side and slack side of the belt is 700 N and 300 N respectively. 4 kg of fuel was consumed in one hour. The indicated mean effective pressure is 6 Bar and the Calorific value of the fuel is 42000 kJ/kg. Calculate the brake power, indicated power, mechanical efficiency, indicated thermal efficiency, and brake thermal efficiency

Given

$i = 1$, $K = 1/2$, $V_s = 6\times10^{-3}\ m^3$, $N = 300\ rpm$, $d_p = 1m$, $T_1 = 700N$

$T_2 = 300N$, $\dot{m}_f = 4\ kg/hr = \frac{4}{3600} = 1.11\times10^{-3}\ kg/s$, $P_m = 6\ Bar$,

$CV = 42000\ KJ/kg$.

To find

(i) BP (ii) IP (iii) η_{mech} (iv) η_{ITH} (v) η_{BTH}

Sol^n

(i) $BP = \frac{2\pi NT}{60000}$

$T = (T_1 - T_2)R_p = (700-300)\times0.5$

$\boxed{T = 200\ N\text{-}m}$

$\therefore BP = \frac{2\pi\times300\times200}{60000}$

$\therefore \boxed{BP = 6.28\ KW}$

(ii) $IP = \left(\frac{10}{6}\right) i\, P_m L A N K$

swept volume, $V_s = AL = 6\times10^{-3}\ m^3$

$\therefore IP = \left(\frac{10}{6}\right)\times1\times6\times6\times10^{-3}\times300\times\frac{1}{2}$

$\boxed{IP = 9\ KW}$

(iii) $\eta_{mech} = \frac{BP}{IP}\times100 = \frac{6.28}{9}\times100 \Rightarrow \boxed{\eta_{mech} = 69.78\%}$

(iv) $\eta_{ITH} = \frac{IP}{\dot{m}_f\times CV}\times100 = \frac{9}{1.11\times10^{-3}\times42000}\times100 \Rightarrow \boxed{\eta_{ITH} = 19.28\%}$

(v) $\eta_{BTH} = \frac{BP}{\dot{m}_f\times CV}\times100 = \frac{6.28}{1.11\times10^{-3}\times42000}\times100 \Rightarrow \boxed{\eta_{BTH} = 13.46\%}$

(11) The following observations were made during a trial on a single cylinder 4-stroke IC engine. Stroke = 300 mm; Bore = 200 mm; Piston speed = 3.5 m/s; Torque = 630 N-m; Mechanical efficiency = 85%; Indicated thermal efficiency = 30%; Calorific value of

Given

$i = 1$, $K = 1/2$, $L = 0.3m$, $D = 0.2m$, $V_p = 3.5$ m/s, $T = 630$ N-m,

$\eta_{mech} = 85\%$, $\eta_{ITH} = 30\%$, $CV = 43900$ kJ/kg.

To find

(i) MEP (ii) $\dot{m}_f$ in kg/hr

Soln

w.k.T

$$IP = \left(\frac{10}{6}\right) i P_m LANK$$

$$\text{Piston speed, } V_p \text{ (m/s)} = \frac{2LN}{60} = 3.5 \text{ (m/s)}$$

$$\therefore LN = \frac{3.5 \times 60}{2}$$

$$\therefore \boxed{LN = 105 \text{ m/min}}$$

$$\boxed{N = 350 \text{ rpm}}$$

$$\eta_{mech} = \frac{BP}{IP} \times 100 \Rightarrow IP = \frac{BP}{\eta_{mech}} \times 100$$

$$BP = \frac{2\pi NT}{60000} = \frac{2 \times \pi \times 350 \times 630}{60000}$$

$$\therefore \boxed{BP = 23.09 \text{ KW}}$$

$$\therefore IP = \frac{23.09}{0.85} \Rightarrow \boxed{IP = 27.16 \text{ KW}}$$

$$27.16 = \left(\frac{10}{6}\right) \times 1 \times P_m \times 150 \times \frac{\pi}{4}(0.2)^2 \times \frac{1}{2}$$

$$\therefore \boxed{P_m = 6.91 \text{ Bar}}$$

(ii)

$$\eta_{ITH} = \frac{IP}{\dot{m}_f \times CV} \times 100 \Rightarrow \dot{m}_f = \frac{27.16}{30 \times 43900} \times 100$$

$$\therefore \boxed{\dot{m}_f = 2.062 \text{ kg/s} = 7.42 \text{ kg/hr}}$$

(12) A six cylinder 4-stroke IC engine develops 50 kW of indicated power at MEP of 700 kPa. The bore and stroke length are 70 mm and 100 mm respectively. If the engine speed is 3700 rpm, find the average misfires per unit time

Given

$i = 6, \quad K = 1/2, \quad IP = 50\,kW, \quad P_m = 700\,KPa = 7\,Bar,$

$D = 0.07\,m, \quad L = 0.1\,m, \quad N = 3700\,rpm.$

To find

No. of miss fires/unit time

Sol^n

Engine speed is given as 3700 rpm

we know that, no. of cycles in 4 stroke engine $\Big\}\ n = NK = 3700 \times \frac{1}{2}$

$n = 1850$

$\therefore$ with the given engine speed,

$$\boxed{\text{Actual No. of explosion per minutes} = 1850}$$

WKT

$$IP = \left(\frac{10}{6}\right) i\, P_m L A N K$$

$$(NK)_{theoretical} = \frac{50 \times 6 \times 4}{10 \times 6 \times 7 \times 0.1 \times \pi \times (0.07)^2}$$

$$\left(\begin{matrix}\text{No. of explosion} \\ \text{Per minute}\end{matrix}\right)_{theorotical} = n_{theorotical} = (NK)_{theor} = 1856$$

$\therefore$ Avg. No. of miss fires/min $= n_{theo} - n_{actual}$

$= 1856 - 1800$

$$\boxed{\therefore \text{Avg. No. of miss fires/min} = 6}$$

(13) Determine the output power of an engine using following data: diameter of brake drum = 1500 mm, speed of the engine = 1260 rad/min, diameter of rope = 20 mm, weight suspended = 100 kg, spring balance reading = 10kg.

Given

$d_b = 1.5m$, $\omega = 1260$ rad/min, $d_r = 0.02m$, $W = 100$ kg,

$S = 10$ kg.

To find

$BP = ?$

Soln

$$BP = \frac{2\pi NT}{60000} \text{ or } \frac{\overset{\text{rad/min}}{\omega} T}{60000} \text{ or } \frac{\overset{\text{rad/sec}}{\omega} T}{1000}$$

$$T = (W-S)R_{eff}$$

$$R_{eff} = \frac{d_b + d_r}{2} = \frac{1.5 + 0.02}{2} = 0.76\,m$$

$$(W-S) = (100-10) = 90\text{ kg} = 90 \times 9.81 = 882.9\,N$$

$$\therefore T = 882.9 \times 0.76$$

$$\boxed{T = 671\ N\text{-}m}$$

$$BP = \frac{\omega T}{60000} = \frac{1260 \times 671}{60000}$$

$$\boxed{BP = 14.09\ kW}$$

(14) The mean diameter of the brake drum of an engine is 1.5m. Its brake power is 14 kW at 21 rad/s. The spring balance pull is 0.1 times the dead load. Find the dead load. Also find the mechanical efficiency of the engine, if its brake thermal efficiency and indicated thermal efficiency are 31.45% and 43% respectively.

Given

$d_b = 1.5m$, $BP = 14kW$, $\omega = 21$ rad/s, $S = 0.1W$, $\eta_{BTH} = 31.45\%$.

$\eta_{ITH} = 43\%$.

To find

$W = ?$, $\eta_{mech} = ?$

Soln

$$BP = \frac{\overset{\text{rad/s}}{\omega} T}{1000} = \frac{21T}{1000} \Rightarrow T = \frac{14 \times 1000}{21} = 666.67kW \quad -(1)$$

$$\therefore T = (W-S)R_{eff} = (W - 0.1W) \times 0.75 = 0.9W \times 0.75 = 0.675W \quad -(2)$$

from eqⁿ ① & ②

$$0.675W = 666.67$$

$$W = \frac{666.67}{0.675}$$

$$\boxed{W = 987.66\ N}$$

(ii) $\eta_{mech} = \frac{BP}{IP} \times 100 = \frac{BP/\dot{m}_f \times CV}{IP/\dot{m}_f \times CV} \times 100$

$$\eta_{mech} = \frac{\eta_{BTH}}{\eta_{ITH}} \times 100$$

$$= \frac{31.45}{43} \times 100$$

$$\boxed{\eta_{mech} = 73.14\%}$$

(15) A 4 cylinder 4-stroke IC engine running at 1000 rpm develops an indicated power of 15 kW. The MEP is 5×10^5 N/m². Find diameter of the cylinder and stroke of piston when the ratio of the diameter to stroke is 0.8.

Given

$i = 4,\ k = 1/2,\ N = 1000$ rpm, $IP = 15$ kW, $P_m = 5\times10^5\ N/m^2$, $= 5$ Bar

$\frac{D}{L} = 0.8.$ or $L = 1.25D$

To find

$D = ?$ $L = ?$

Solⁿ

$$IP = \left(\frac{10}{6}\right) i P_m L A N K$$

$$15 = \left(\frac{10}{6}\right) \times 4 \times 5 \times 1.25D \times \frac{\pi}{4} D^2 \times 1000 \times \frac{1}{2}$$

$$\therefore D^3 = 9.167 \times 10^{-4}\ m^3$$

$$\boxed{\therefore D = 0.0971\ m \text{ or } 97.1\ mm}$$

$$L = 1.25D = 1.25 \times 0.0971$$

$$\boxed{\therefore L = 0.1214\ m \text{ or } 121.4\ mm}$$

(16) A 4-stroke petrol engine of 100 mm bore and 150 mm stroke consumes 1kg of fuel per hour, MEP is 7 Bar, indicated thermal efficiency is 30%, calorific value of fuel is 40 MJ/kg. Determine the crank speed.

Given

$i=1,\ K=1/2,\ D=0.1m,\ L=0.15m,\ \dot{m}_f=1kg/hr=2.78\times10^{-4}\frac{kg}{s},$

$\eta_{ITH}=30\%,\ CV=40\,MJ/kg=40000\,J/kg,\ P_m=7\,Bar$

To find

$N=?$

Sol^n

$IP=\left(\frac{10}{6}\right) i P_m LANK$

$\eta_{ITH}=\frac{IP}{\dot{m}_f \times CV}\times100 \Rightarrow IP=\frac{\eta_{ITH}\times\dot{m}_f\times CV}{100}$

$\therefore IP=\frac{30\times2.78\times10^{-4}\times40000}{100}$

$\boxed{IP=3.336\,KW}$

$3.336=\left(\frac{10}{6}\right)\times1\times7\times0.15\times\frac{\pi}{4}\times(0.1)^2\times N\times\frac{1}{2}$

$\therefore \boxed{N=485.43\,rpm\approx485\,rpm}$

(17) During the test on a 4-stroke IC engine, the following observation were taken when running at full load.

Area of indicator diagram = 3 cm^2; length of the indicator diagram = 5 cm; Spring constant = 100 N/cm^2/cm; Engine crank shaft speed = 500 rpm, diameter of the cylinder = 150 mm; stroke of the piston = 200 mm; Determine the

Given

$i=1,\ K=1/2,\ a=3cm^2,\ l=5cm,\ N=500\,rpm,\ D=0.15m$

$L=0.2m,\ S=100\,N/cm^2/cm=100\times10^4\,N/m^2/cm=10\,Bar/cm$

To find

$IP=?$

$\underline{\underline{\text{sol}^n}}$

$$IP = \left(\frac{10}{6}\right) i\, P_m L A N K$$

$$P_m = \frac{Sa}{l} = \frac{10(\text{Bar/cm}) \times 3}{5}$$

$$\boxed{P_m = 6 \text{ Bar}}$$

$$IP = \left(\frac{10}{6}\right) \times 1 \times 6 \times 0.2 \times \frac{\pi}{4}(0.15)^2 \times 500 \times \frac{1}{2}$$

$$\therefore \boxed{IP = 8.836 \text{ KW}}$$

Exercises

(18) A single cylinder 4-stroke IC engine has a bore of 180 mm, stroke of 200 mm and a rated speed of 300 rpm. Torque on the brake drum is 200 Nm and MEP is 6 Bar. It consumes 4 kg of fuel in one hour. The Calorific value of the fuel is 42000 kJ/kg.

(19) The following are the details of a 4-stroke petrol engine.

Diameter of the brake drum = 60 cm; Full brake load on drum = 250 N;
Brake drum speed = 450 rpm; Calorific value of petrol = 40 MJ/kg;
Brake thermal efficiency = 32%; Mechanical efficiency = 80% and Specific gravity of petrol = 0.82. Determine BP, IP, Fuel consumed in liters per second,

(20) Determine the indicated power of a 4-stroke petrol engine which has an average piston speed of 70 m/min. The MEP is 5.5 bar and diameter of piston is 150 mm

(21) A four-cylinder four stroke petrol engine develops 200 kW brake power at 2500 rpm. Stroke to bore ratio is 1.2. If mean effective pressure is 10 bar and mechanical efficiency is 81%, calculate bore and stroke of the engine. Also calculate the indicated thermal efficiency and brake thermal efficiency if 65 kg/hr of petrol is consumed having calorific value of 42000 kJ/kg.

(22) A 4-stroke single cylinder IC engine of 250 mm diameter and 400 mm of stroke runs at a piston speed of 8 m/s. If the engine develops 50 kW indicated power, determine MEP and speed of the crank shaft.

(23) Determine indicated power of a 4-stroke engine with swept volume of 6 liters and running at 1000 rpm. MEP is 600 kN/m^2.

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