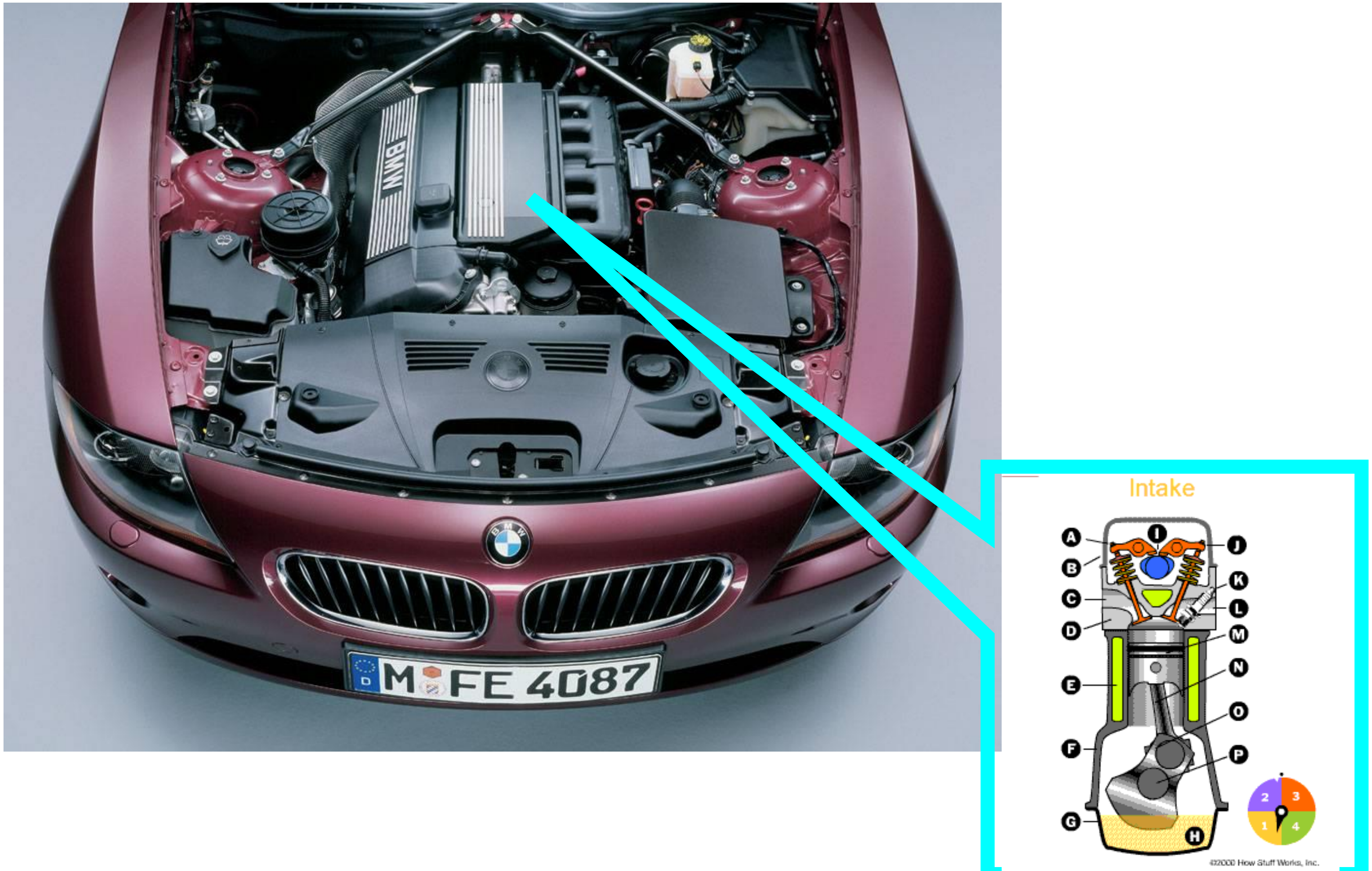
INTERNAL COMBUSTION ENGINES (I C ENGINES)



INSPIRED BY LIFE

Heat Engine

Heat Engine is a ***prime mover*** which derives the heat energy from ***combustion of fuel*** or any other source and converts this energy into mechanical work.

Mechanical work produced in Heat Engines is ***Linear Work (Motion)*** which is converted into ***Rotary Work (Motion)*** by elements such as cylinder, piston, connecting rod, crank, etc.

Note: Prime Mover is a device which utilizes a natural source of energy to produce ***rotary*** mechanical energy.

Classification of Heat Engines

Heat Engines may be classified as:

1. External Combustion Engines (E.C. Engines)

Combustion of fuel takes place ***outside the engine cylinder***.

Example: Steam Engine, Steam turbine, etc.

2. Internal Combustion Engines (I.C. Engines)

Combustion of fuel takes place ***inside the engine cylinder***.

Example: Petrol Engine, Diesel Engine, etc.

INSPIRED BY LIFE

Comparing between E.C. & I.C. Engines

I.C. Engine	*E.C. Engine*
1. Combustion of fuel takes place *inside the engine cylinder*.	1. Combustion of fuel takes place *outside the engine cylinder.*
2. The temperature inside the combustion chamber is much *higher*.	2. The working temperature and pressure inside the combustion chamber is *low.*
3. Cooling arrangement is necessary to *prevent overheating* of the cylinder.	3. The cylinder must be insulated to *prevent the loss of heat* to the surroundings.

Comparing between E.C. & I.C. Engines – contd.

I.C. Engine	*E.C. Engine*
4. Thermal efficiency is higher (35 to 40%)	4. Thermal efficiency is lower (15 to 20%)
5. It can be started instantaneously.	5. It cannot be started instantaneously.
6. I.C. Engines are of *single acting type*.	6. Reciprocating steam engines generally are of *double acting type.*
7. Used for *transport vehicles*	7. Used for *electric power generation*

Classification of IC Engines

According to:

(i) Nature of Thermodynamic Cycle:

- Otto cycle engine
- Diesel cycle engine
- Dual combustion cycle engine

(ii) Type of the Fuel used:

- Petrol engine
- Diesel engine
- Gas engine
- Bio-fuel engine
- Dual fuel engine

Classification of IC Engines–Contd.

(iii) Number of Strokes:

- two - Stroke Engine
- four- Stroke Engine

(iv) Method of Ignition:

- Spark Ignition Engine (S.I. Engine)
- Compression Ignition Engine (C.I. Engine)

(v) Number of Cylinders:

- Single Cylinder Engine
- Multi-Cylinder Engine

Classification of IC Engines–Contd.

(vi) Position of the Cylinder:

- Horizontal engine
- Vertical engine
- V- engine
- In-line engine
- Opposed cylinder engine
- Radial engine

(vii) Method of Cooling:

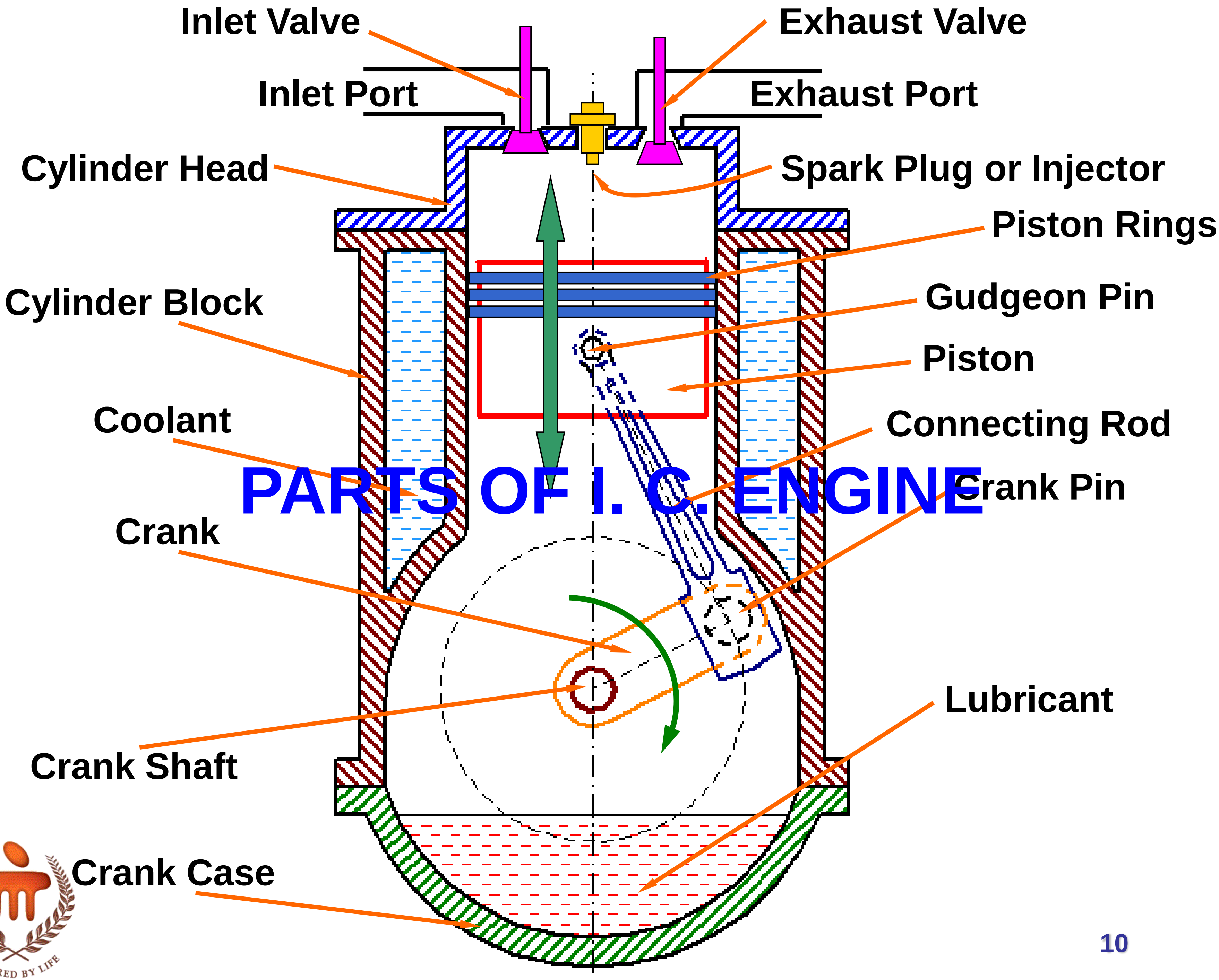
- Air cooled engine
- Water cooled engine

Classification of IC Engines–Contd.

(viii) Speed of the Engine:

- Low Speed Engine
- Medium Speed Engine
- High Speed Engine

PARTS OF I. C. ENGINE



I. C. Engine terms & Definitions

1. Dead Centers:

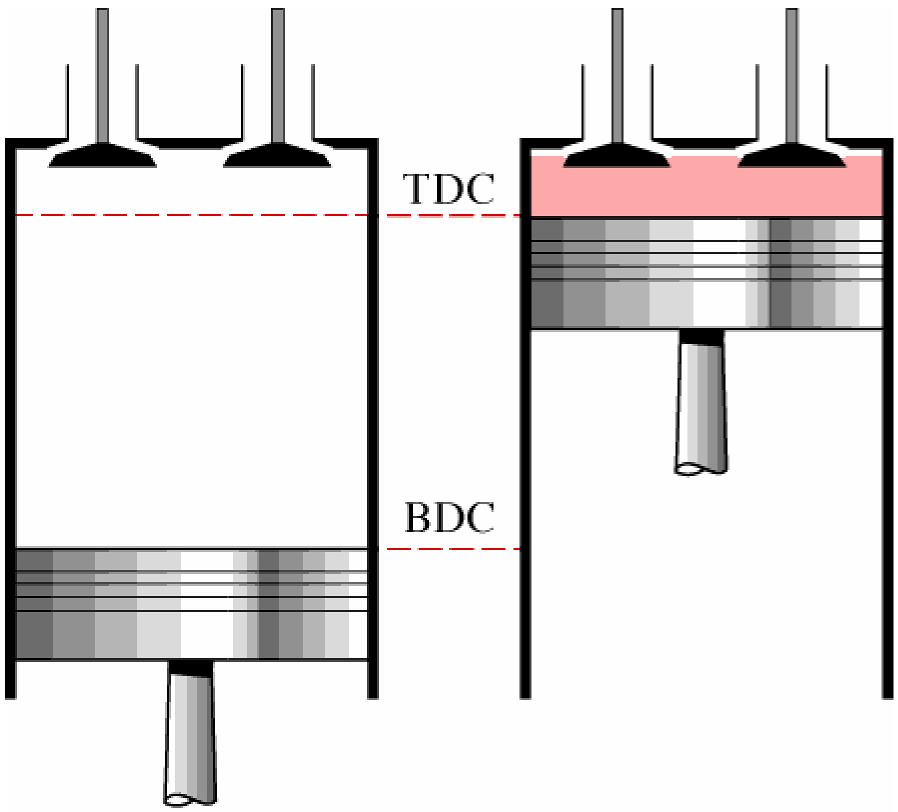
These are two positions of the piston when the crank and connecting rod are in line.

(a) Top Dead Center (TDC):

- It is the top most position of the piston towards head side of the cylinder.
- It is also known as the ***Cover End***

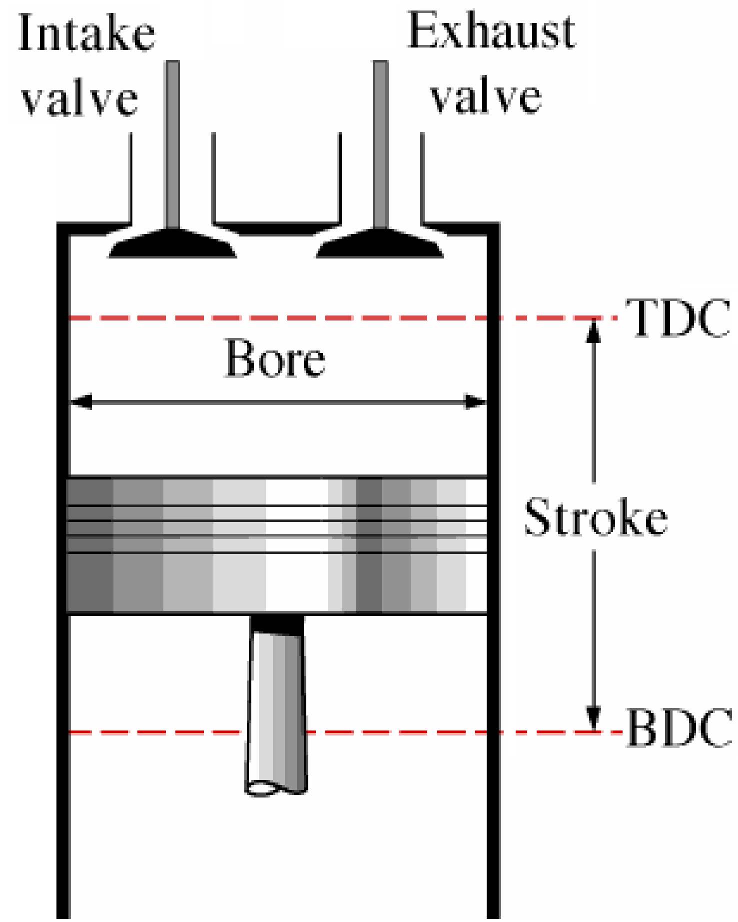
(b) Bottom Dead Center (BDC):

- It is the lowermost position of the piston towards the crank end side of the cylinder.
- It is also known as the ***Crank End***



2. Stroke (L):

It is the linear distance travelled by the piston when it moves from one end of the cylinder to the other end. (TDC to BDC or BDC to TDC)

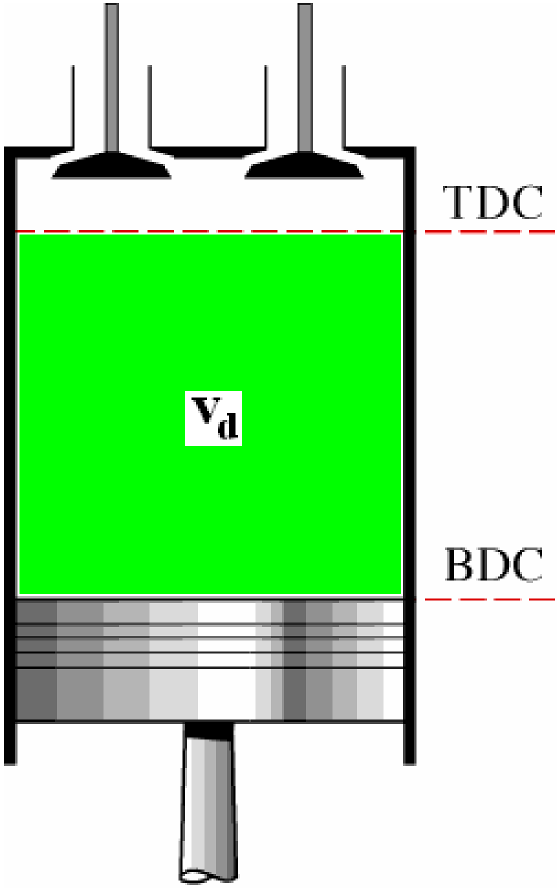


3. Bore (d):

It is the inside diameter of the cylinder.

4. Swept volume or Displacement volume (v_d):

It is the volume swept through by the piston in moving between TDC and BDC



(*a*) Displacement volume

5. Clearance volume (v_c):

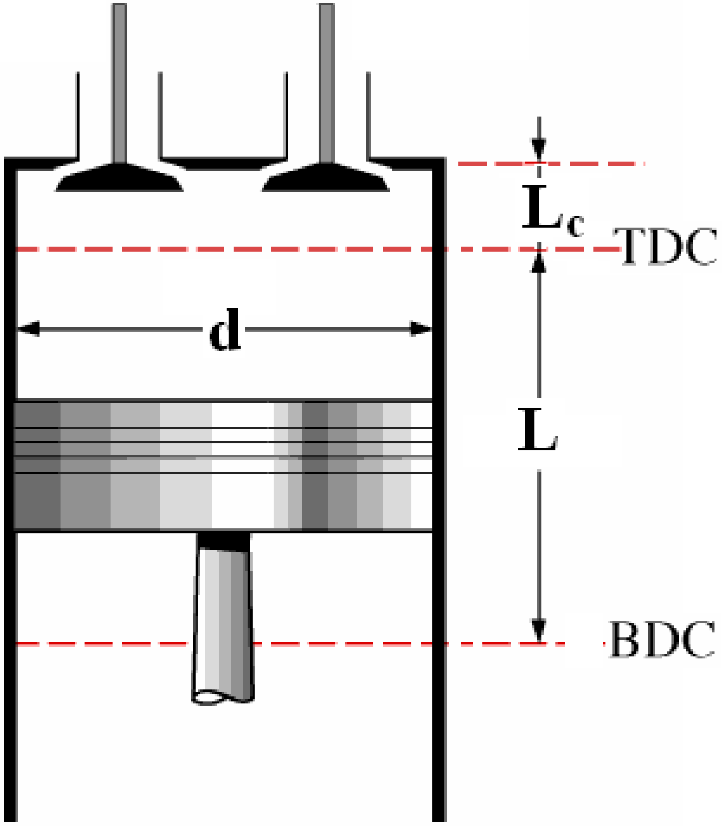
It is the volume contained in the cylinder above the top of the piston, when the piston is at TDC.

$\therefore$ Total volume = Swept volume + Clearance volume.

$v_{tot} = v_d + v_c$

$$v_{tot} = \frac{\pi d^2}{4} \times L + \frac{\pi d^2}{4} \times L_c$$

$$= \frac{\pi d^2}{4} \times (L + L_c)$$



6. Compression ratio "r" :

It is defined as the ratio of total cylinder volume (v_{tot}) to clearance volume (v_c).

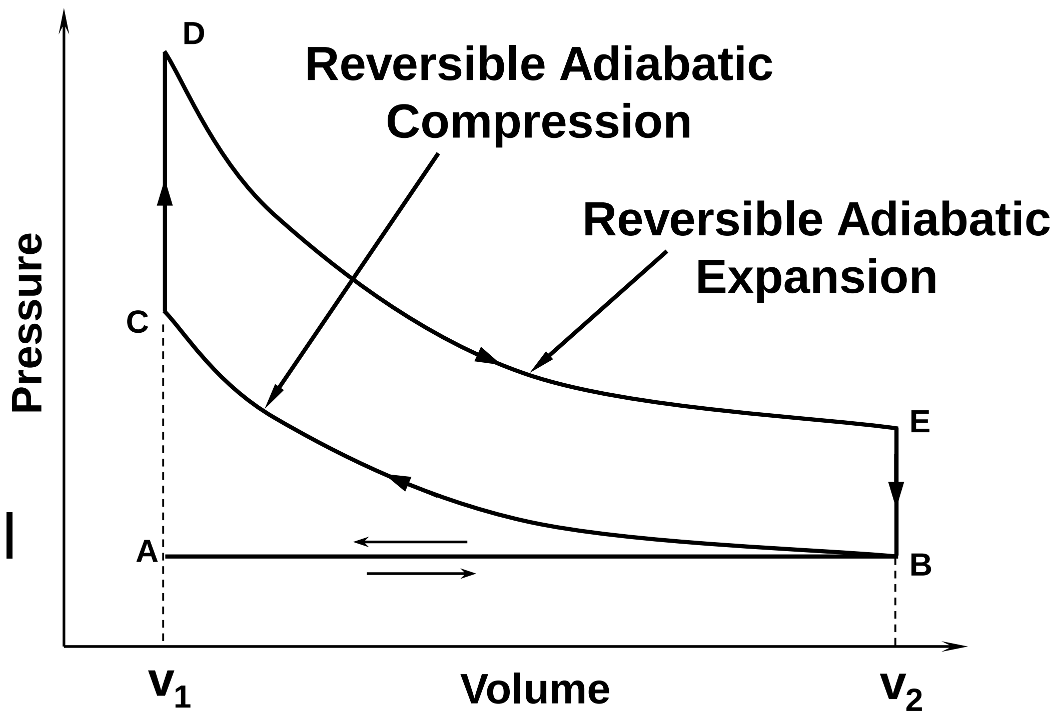
$$Compression\ Ratio\,(r) = \frac{Total\ Volume}{Clearance\,Volume} = \frac{(v_d + v_c)}{v_c}$$

Value of "r" for,

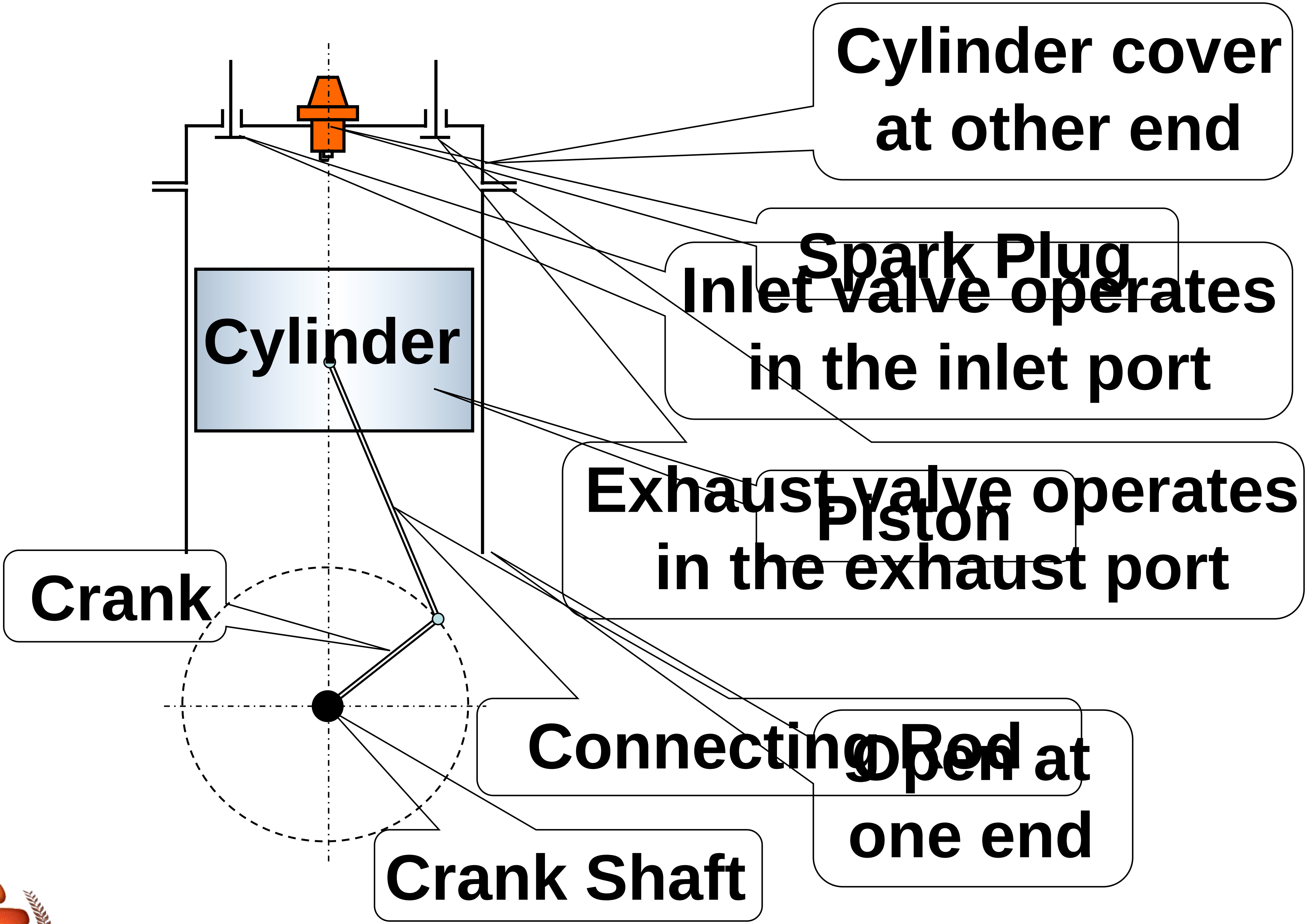
Petrol engine lies between	7	and	12
Diesel engine lies between	16	and	20

Working of 4-S Petrol Engine

- The petrol engines work on the principle of **“ OTTO CYCLE”** also known as ***Constant Volume Cycle.***
- The engines operating on this cycle use either petrol or other spirit fuels or the gases such as LPG / CNG as their fuels..



Theoretical Otto cycle

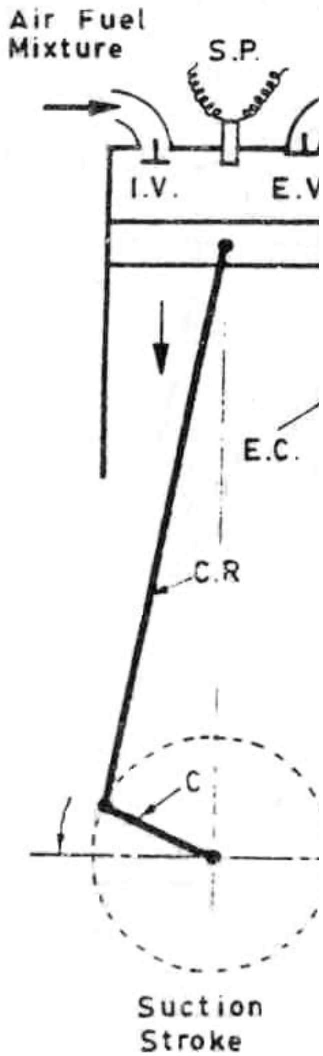

Cylinder cover at other end
Spark Plug
Inlet valve operates in the inlet port
Cylinder
Exhaust valve operates in the exhaust port
Piston
Crank
Connecting Rod
Open at one end
Crank Shaft

- The piston performs ***four strokes*** to complete ***one working cycle.***
    1. Suction stroke
    2. Compression stroke
    3. Working or power stroke, and
    4. Exhaust stroke
- A spark plug is used to produce a spark so as to ignite the charge inside the cylinder.
- Since ignition in these engines is due to a spark, they are also called ***Spark Ignition Engines (S.I. Engines).***

- In a 4-Stroke petrol engine, the ***charge*** admitted into the engine cylinder is a ***homogeneous mixture of petrol and air.***

- Depending on the load on the engine, petrol and air is mixed in proper proportions and sent into the cylinder by a popular device known as ***"carburettor".***

Schematic of Four-S Petrol Engine

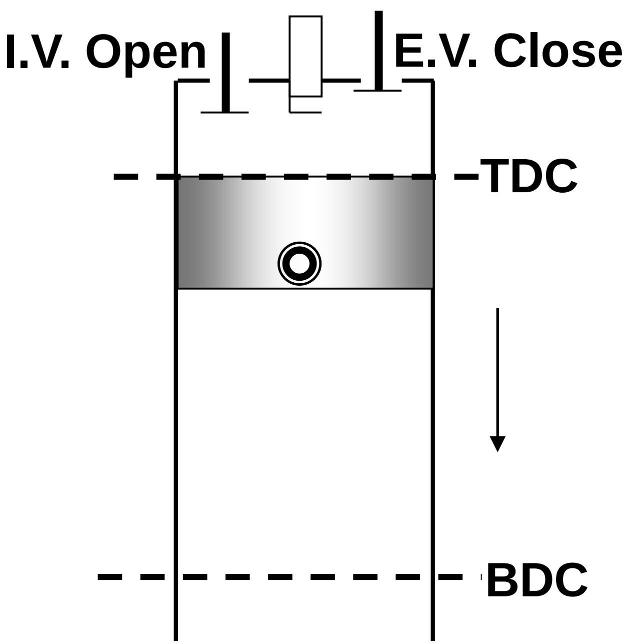


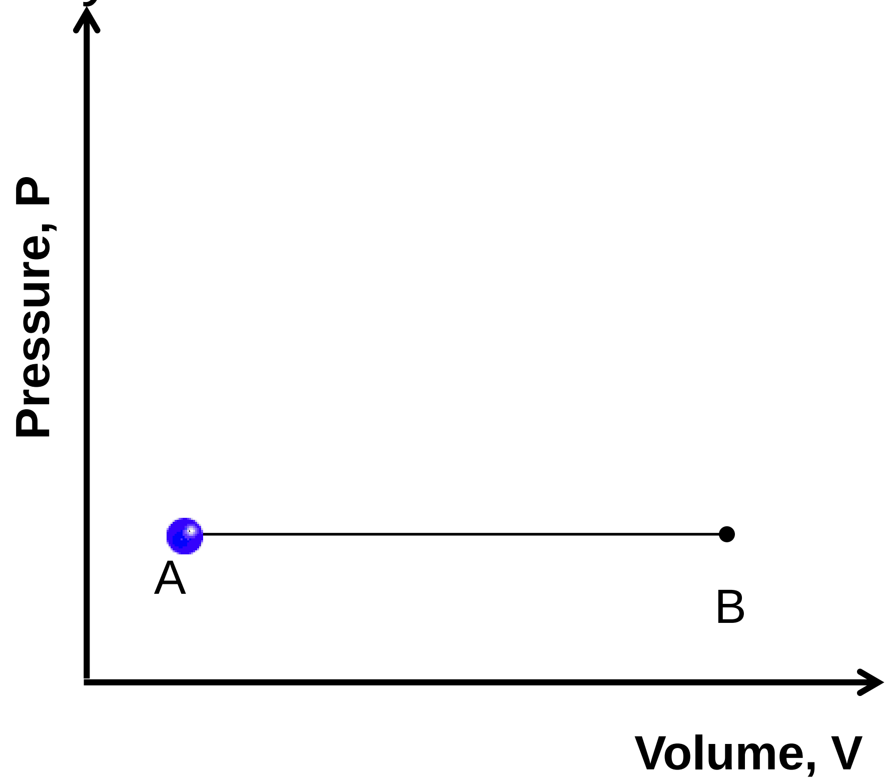
us:
s

I.V. = Inlet Valve, E.V. = Exhaust Valve, E.C. = Engine Cylinder, C.R. = Connecting Rod
C = Crank S.P = Spark Plug.

Suction Stroke: During the suction stroke, inlet valve is open and exhaust valve closed.

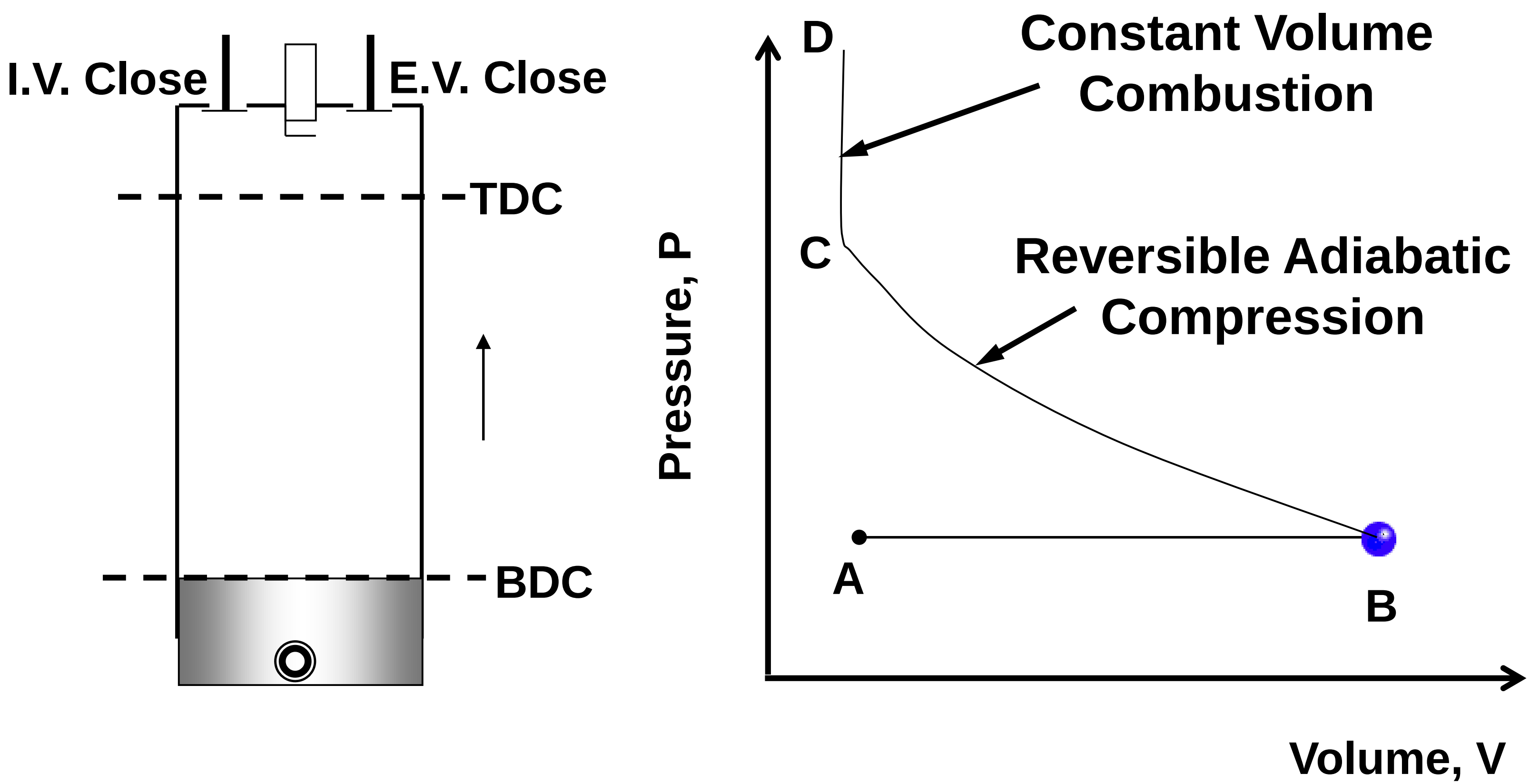
- The piston moves from TDC to BDC, drawing a fresh charge of vaporized fuel-air mixture. Crank shaft rotates by half a rotation.
- This stroke is represented by the line AB on the P-V diagram.





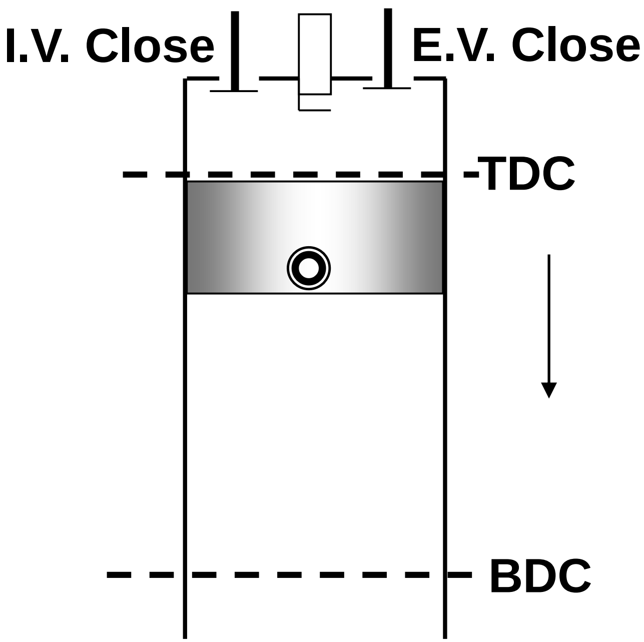
Compression Stroke: During compression stroke, both inlet & exhaust valves are closed.

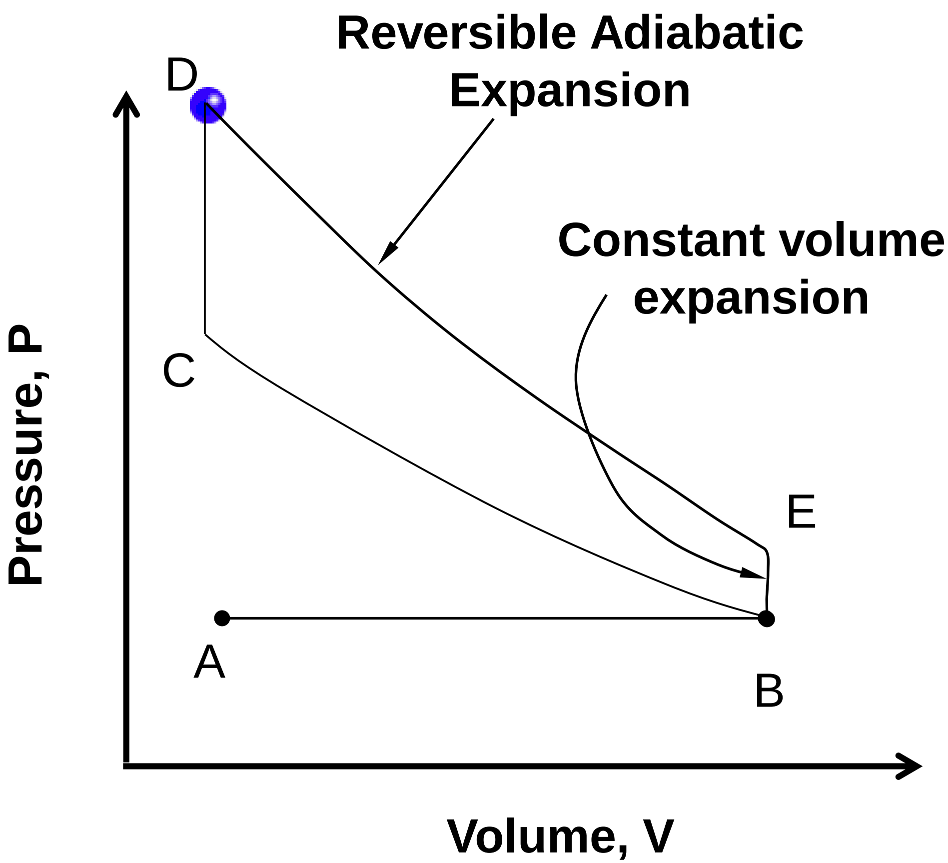
- The piston moves from BDC to TDC, thus compressing air petrol mixture. Crank shaft rotates by half a rotation.
- Due to compression, the pressure and temperature of the charge are increased. This is shown by the line BC on the P- V diagram which is ***"Adiabatic Compression".***
- Just before the end of this stroke the spark - plug initiates a spark which ignites the compressed charge and ***combustion takes place at constant volume*** as shown by the line CD.


I.V. Close
E.V. Close
TDC
BDC
D
C
A
B
Constant Volume Combustion
Reversible Adiabatic Compression
Pressure, P
Volume, V

Working Stroke: During working stroke, both inlet & exhaust valves are closed.

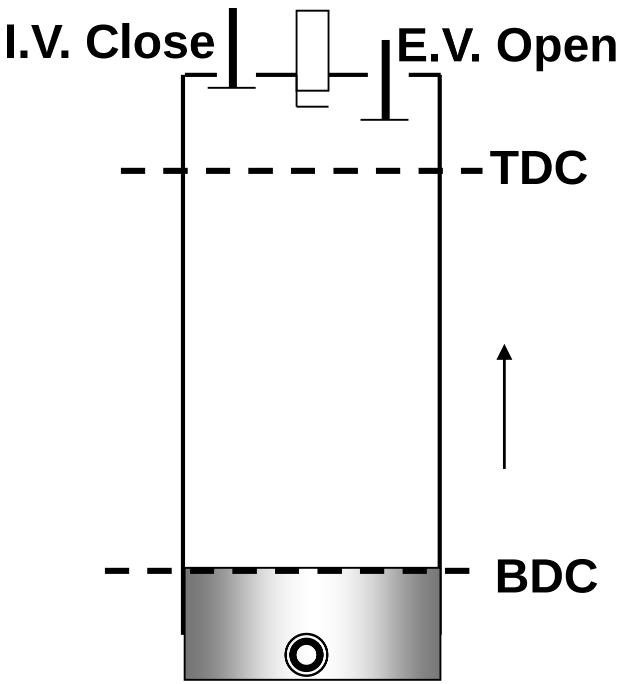
- The burnt gases expand and cause the piston to move from TDC to BDC. Crank shaft rotates by half a rotation.
- The high pressure burnt gases exert pressure on the piston and force it to move from TDC to BDC producing ***Linear Work.***
- Connecting rod and crank convert this linear work into ***Rotary Work*** of the crank shaft.
- The burnt gases expand as the piston moves. Expansion of gases is an ***"Adiabatic Expansion"*** process which is shown by the line DE on the P-V diagram.
- Just before the piston reaches BDC, the exhaust valve opens causing sudden release of gases to atmosphere.
- There is sudden ***drop in pressure at constant volume*** inside cylinder as shown by line EB on the P-V diagram.

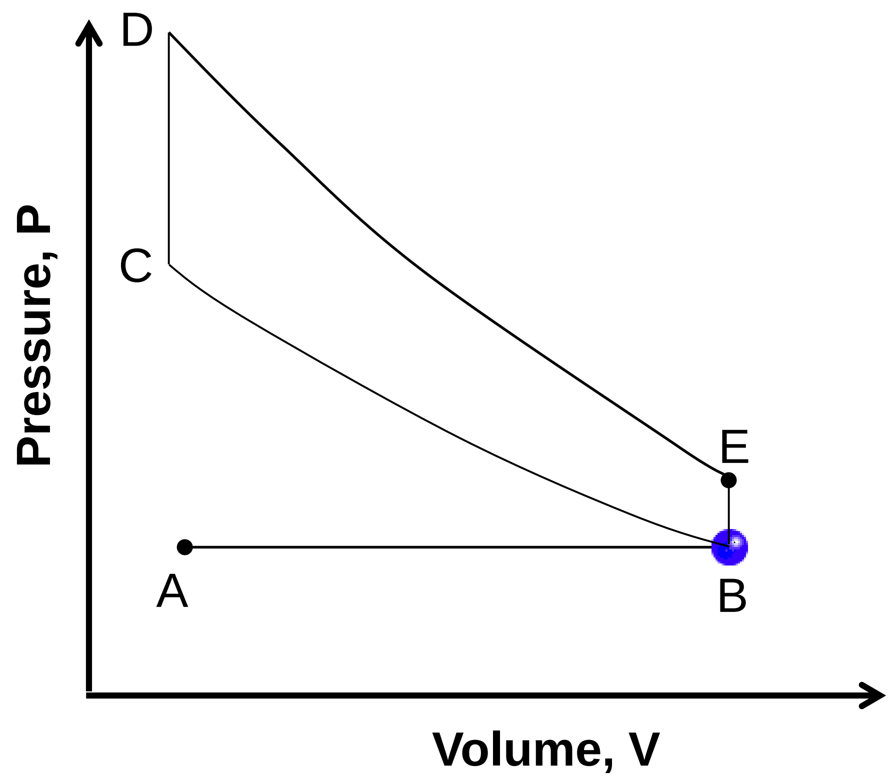

I.V. Close
E.V. Close
TDC
BDC


Reversible Adiabatic Expansion
Constant volume expansion
D
C
E
A
B
Pressure, P
Volume, V

Exhaust Stroke: During the exhaust stroke the exhaust valve is open and inlet remains closed.

- During this stroke the piston moves from BDC to TDC and pushes the remaining gases to the atmosphere.
- This stroke is represented the line BA on the P-V diagram.



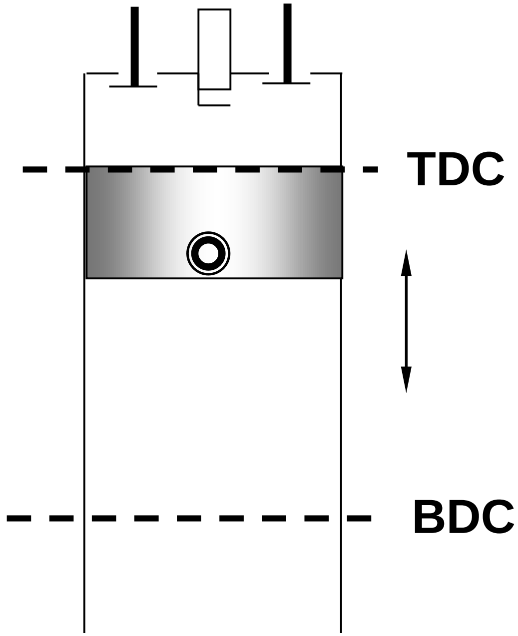


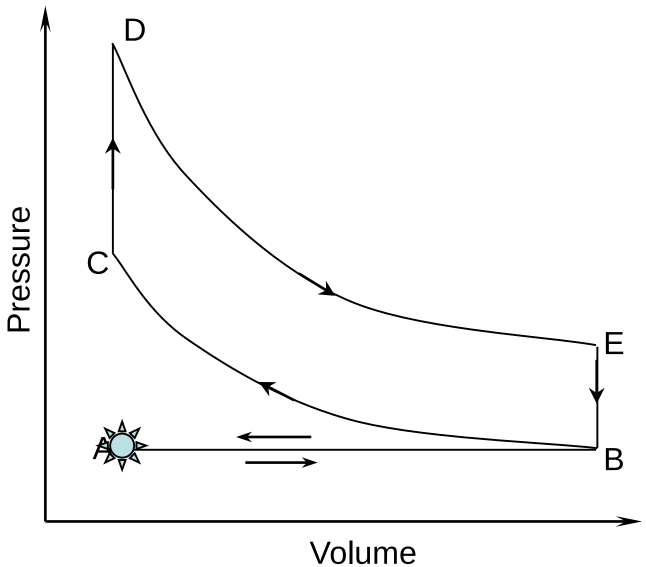
Concluding Remarks on working of 4S Petrol Engine

- This engine requires 4 strokes to complete one working cycle.
- The crank shaft makes two revolutions to complete one cycle (half revolution per stroke).
- Power is developed in alternate revolutions of the crankshaft.
- Energy developed during power stroke is stored in the ***flywheel.*** Energy required to perform suction, compression and exhaust stroke is provided from the flywheel.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

Flywheel is a heavy disc rigidly keyed to the crank shaft

P V Diagram for SI Engine / Otto Cycle Engine



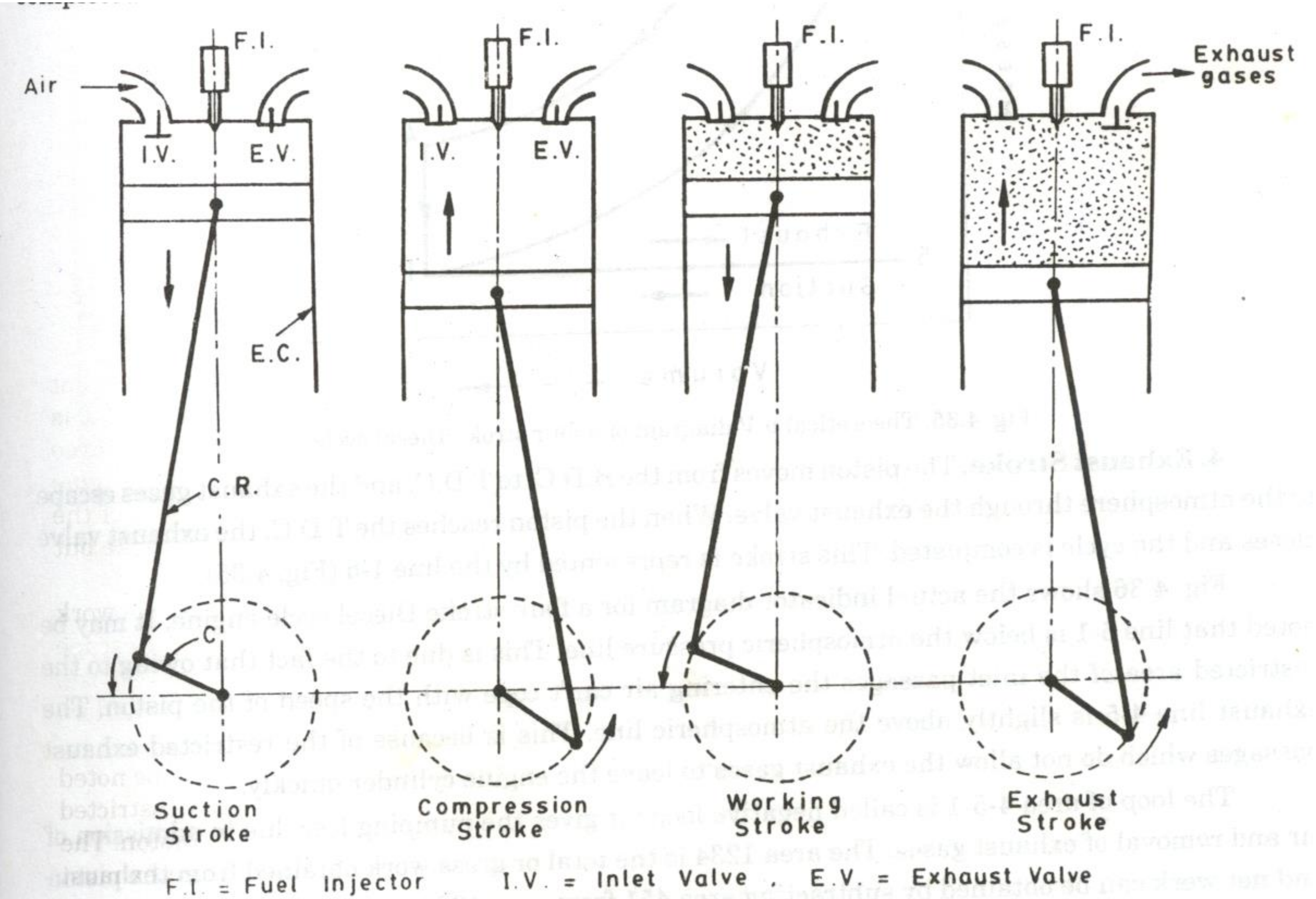


Theoretical Otto cycle

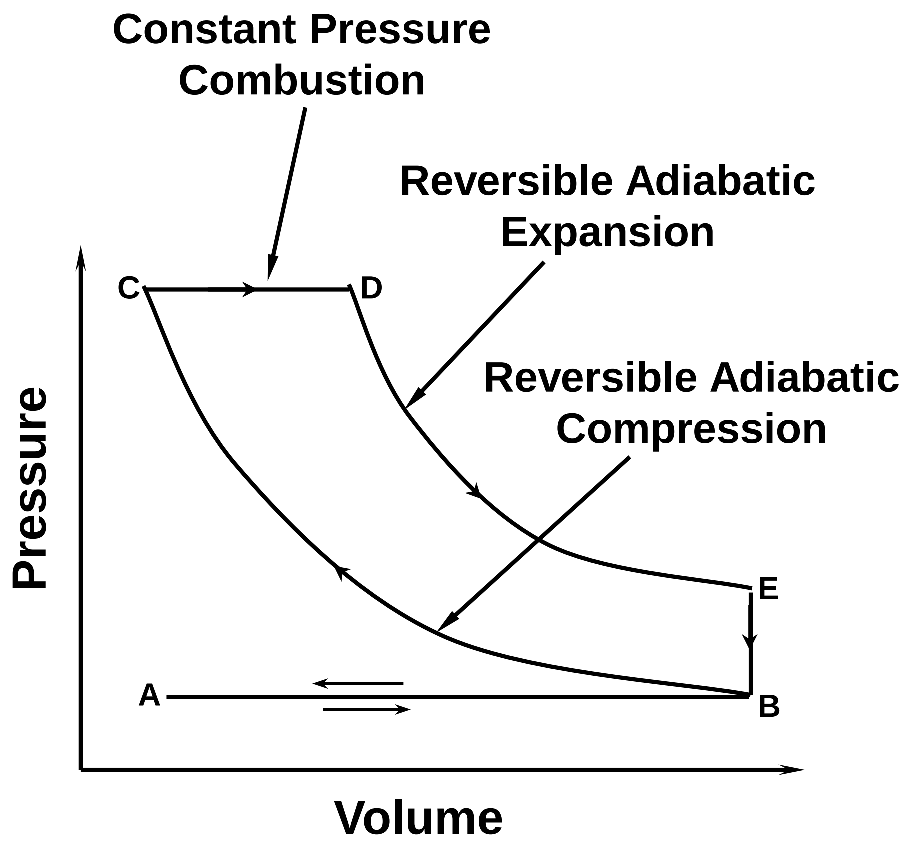
Working of 4S Diesel Engine

- The basic construction of a four stroke diesel engine is same as that of four stroke petrol engine.
- Instead of a spark plug, a ***Fuel Injector*** is mounted in its place.
- Instead of a carburettor, a ***fuel pump*** supplies the fuel oil to the fuel injector at higher pressure.
- The fuel injector injects the fuel into the cylinder as a fine spray at very high pressure at the beginning of power stroke.

- In case of diesel engine, only air enters the cylinder during suction stroke, i.e., ***charge is only air.***
- So, only air is compressed during the compression stroke.
- At the end of the compression stroke, the fuel injector injects diesel into the cylinder in the form of fine spray.
- When this fine spray of diesel comes in contact with hot compressed air in the cylinder, it auto ignites and results in the combustion of injected diesel fuel.
- Since ignition in these engines is due to the high temperature of the compressed air, they are called as ***Compression Ignition Engines (C.I. Engines).***


F.I.
Air
I.V.
E.V.
E.C.
C.R.
C
Suction Stroke
Compression Stroke
Working Stroke
Exhaust Stroke
Exhaust gases
F.I. = Fuel Injector
I.V. = Inlet Valve
E.V. = Exhaust Valve

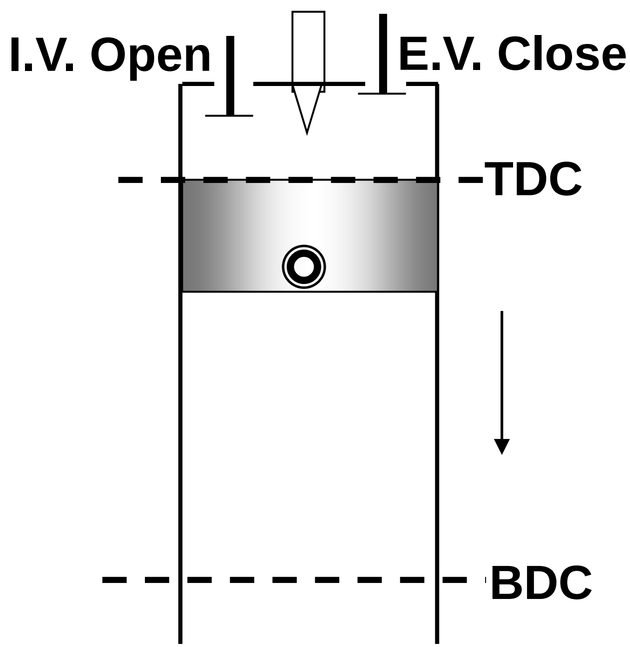
- The diesel engines work on the principle of **“ DIESEL CYCLE”** also known as ***Constant Pressure Cycle.***
- The engines operating on this cycle use either diesel fuel or other spirit fuels or bio-fuels..

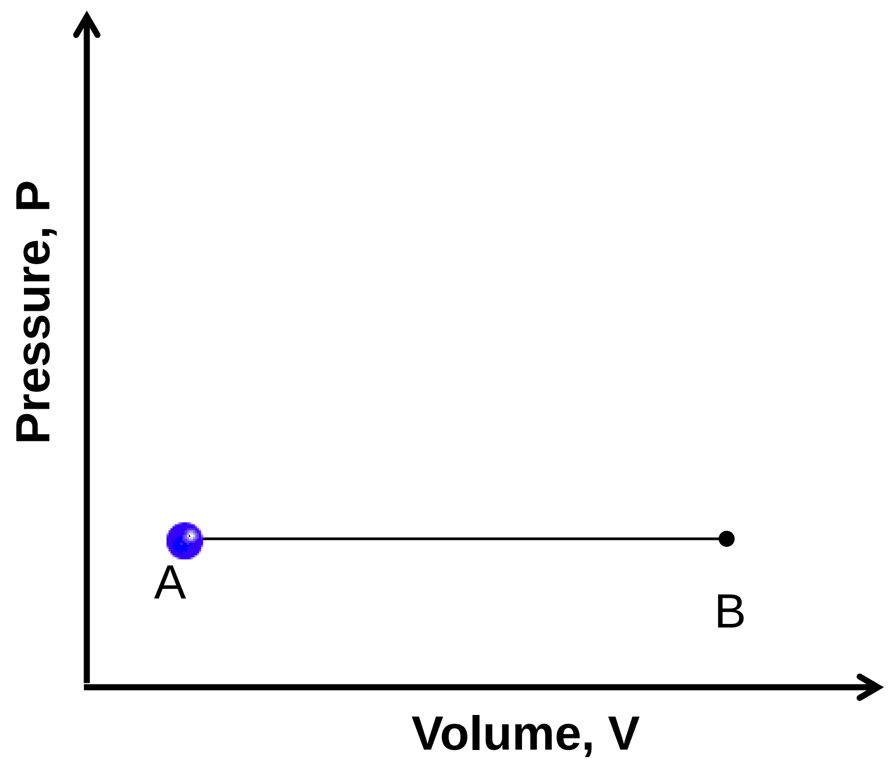


Theoretical Diesel cycle

Suction Stroke: During the suction stroke, inlet valve is open and exhaust valve closed.

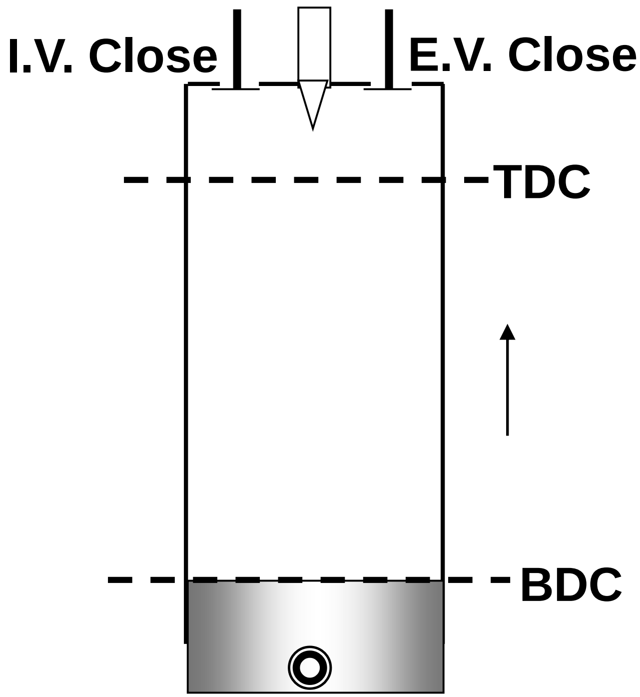
- The piston moves from TDC to BDC, drawing a fresh charge of air only. Crank shaft rotates by half a rotation.
- This stroke is represented by the horizontal line AB on the P-V diagram.

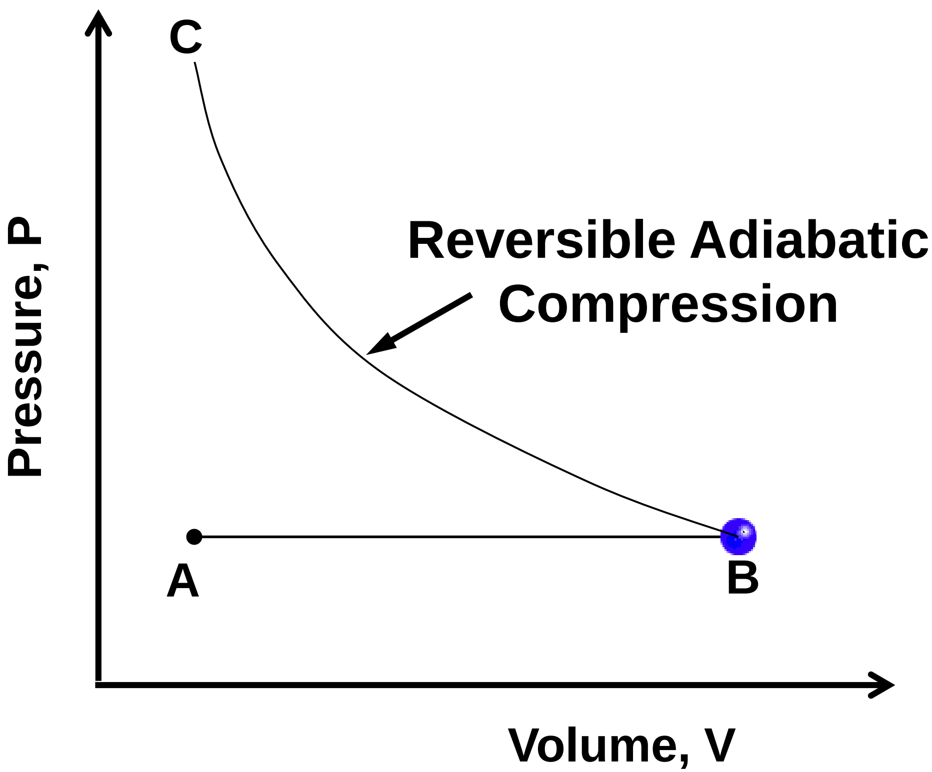




Compression Stroke: During compression stroke, both inlet & exhaust valves are closed.

- The piston moves from BDC to TDC, thus compressing air. Crank shaft rotates by half a rotation.
- Due to compression, the pressure and temperature of air are increased. This is shown by the curved line BC on the P-V diagram which is ***"Adiabatic Compression".***

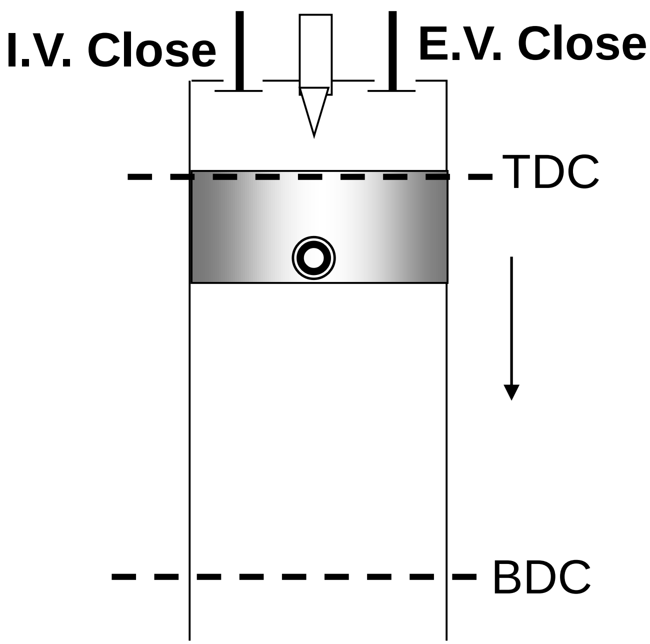

I.V. Close
E.V. Close
TDC
BDC


Pressure, P
Volume, V
C
A
B
Reversible Adiabatic Compression

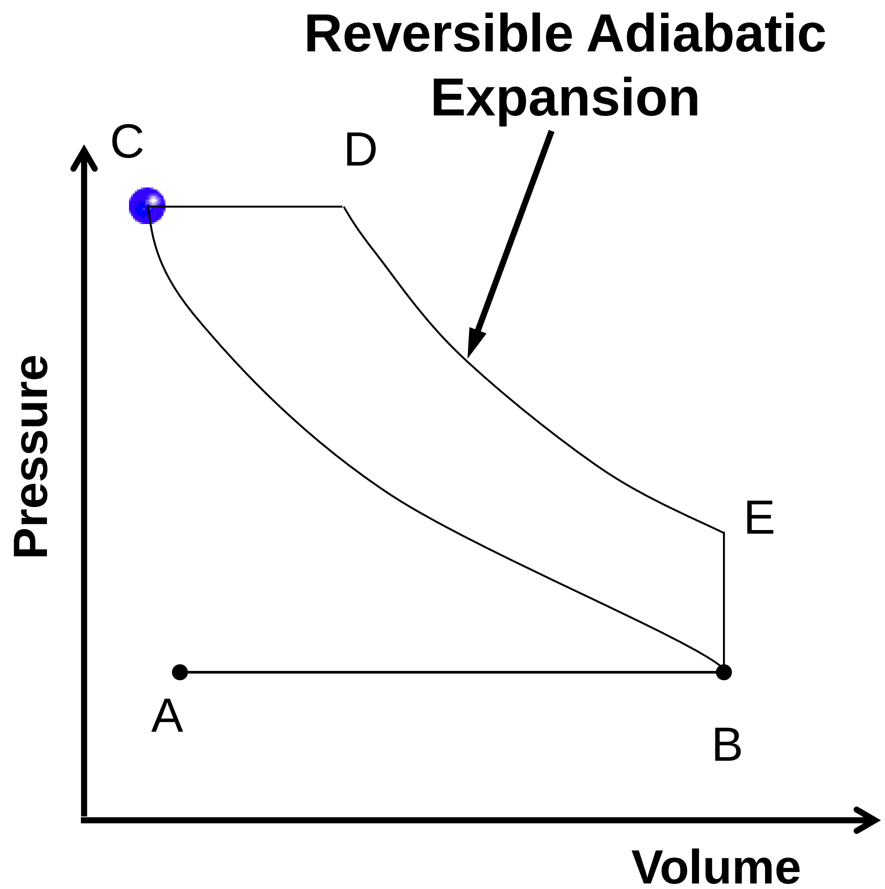
Working Stroke: During working stroke, both inlet & exhaust valves are closed.

- The burnt gases expand and cause the piston to move from TDC to BDC. Crank shaft rotates by half a rotation.
- Just at the beginning of this stroke, the fuel injector continuously injects a metered quantity of diesel in the form of a fine spray into the hot compressed air.
- The temperature of compressed air is sufficient to ignite the diesel being sprayed. So, ***combustion takes place at constant pressure.***
- Partial expansion of burnt gases at constant pressure causes the initial movement of the piston as shown by the horizontal line CD on the P-V diagram.
- The piston is forced further during the remaining part of this stroke only due to the expansion of burnt gases.

- Expansion of gases is an ***"Adiabatic Expansion"*** process which is shown by the curved line DE on the P-V diagram.
- Connecting rod and crank converts the ***Linear Work*** of the piston into ***Rotary Work*** of the crank shaft.
- Just before the piston reaches BDC, the exhaust valve opens causing sudden release of gases to atmosphere.
- There is sudden ***drop in pressure at constant volume*** inside cylinder as shown by the vertical line EB on the P-V diagram.



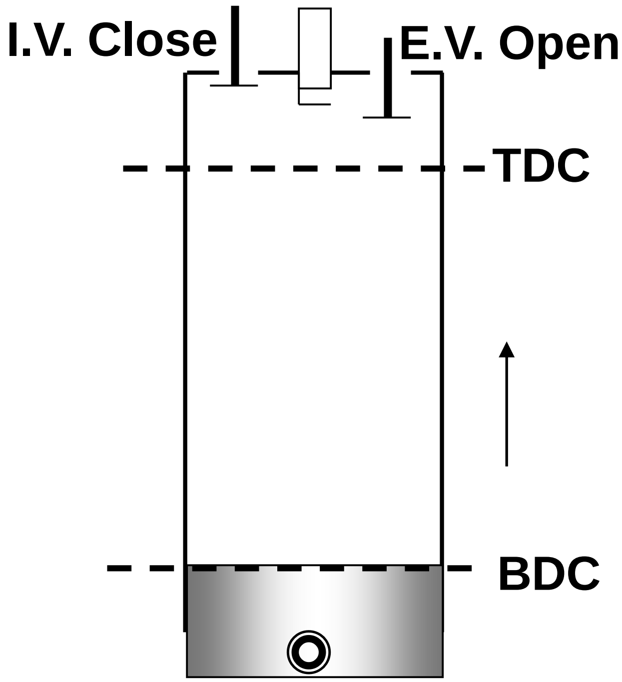
I.V. Close
E.V. Close
TDC
BDC

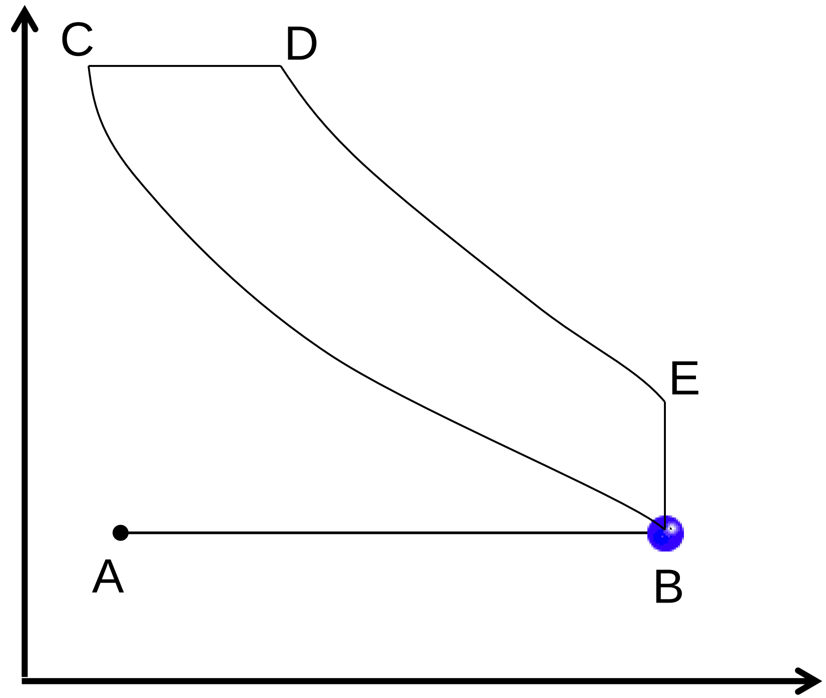


Reversible Adiabatic Expansion
C
D
E
A
B
Pressure
Volume

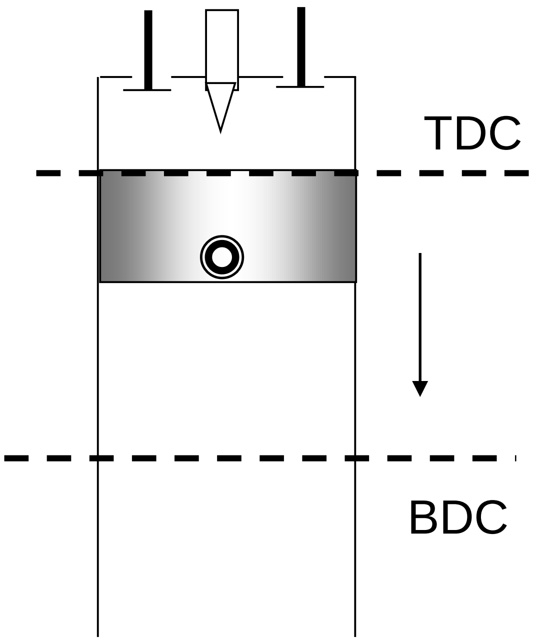
Exhaust Stroke: During the exhaust stroke the exhaust valve is open and inlet remains closed.

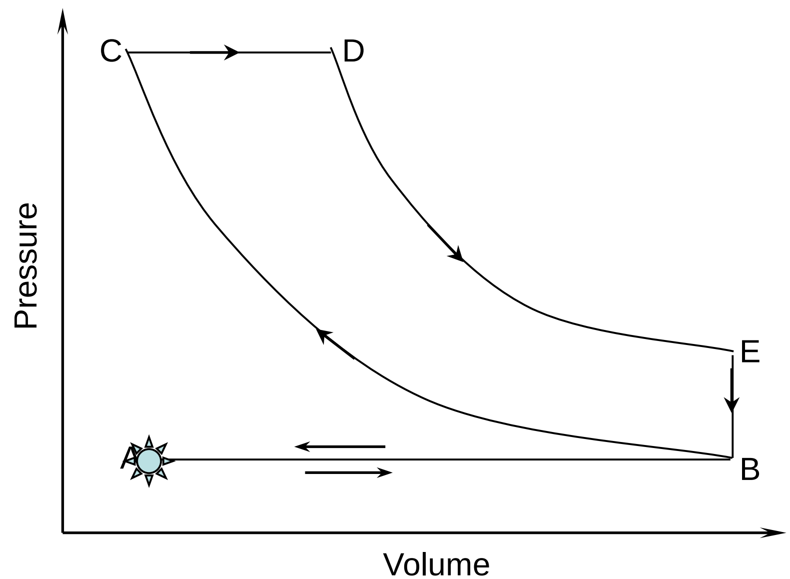
- During this stroke the piston moves from BDC to TDC and pushes the remaining gases to the atmosphere.
- This stroke is represented the line horizontal BA on the P-V diagram.





P V Diagram for C.I. Engine / Diesel Cycle Engine





Theoretical Diesel cycle

Concluding Remarks on working of 4S Diesel Engine

- This engine requires 4 strokes to complete one working cycle.
- The crank shaft makes two revolutions to complete one cycle (half revolution per stroke).
- Power is developed in alternate revolutions of the crankshaft.
- Energy developed during power stroke is stored in the ***flywheel.*** Energy required to perform suction, compression and exhaust stroke is provided from the flywheel.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

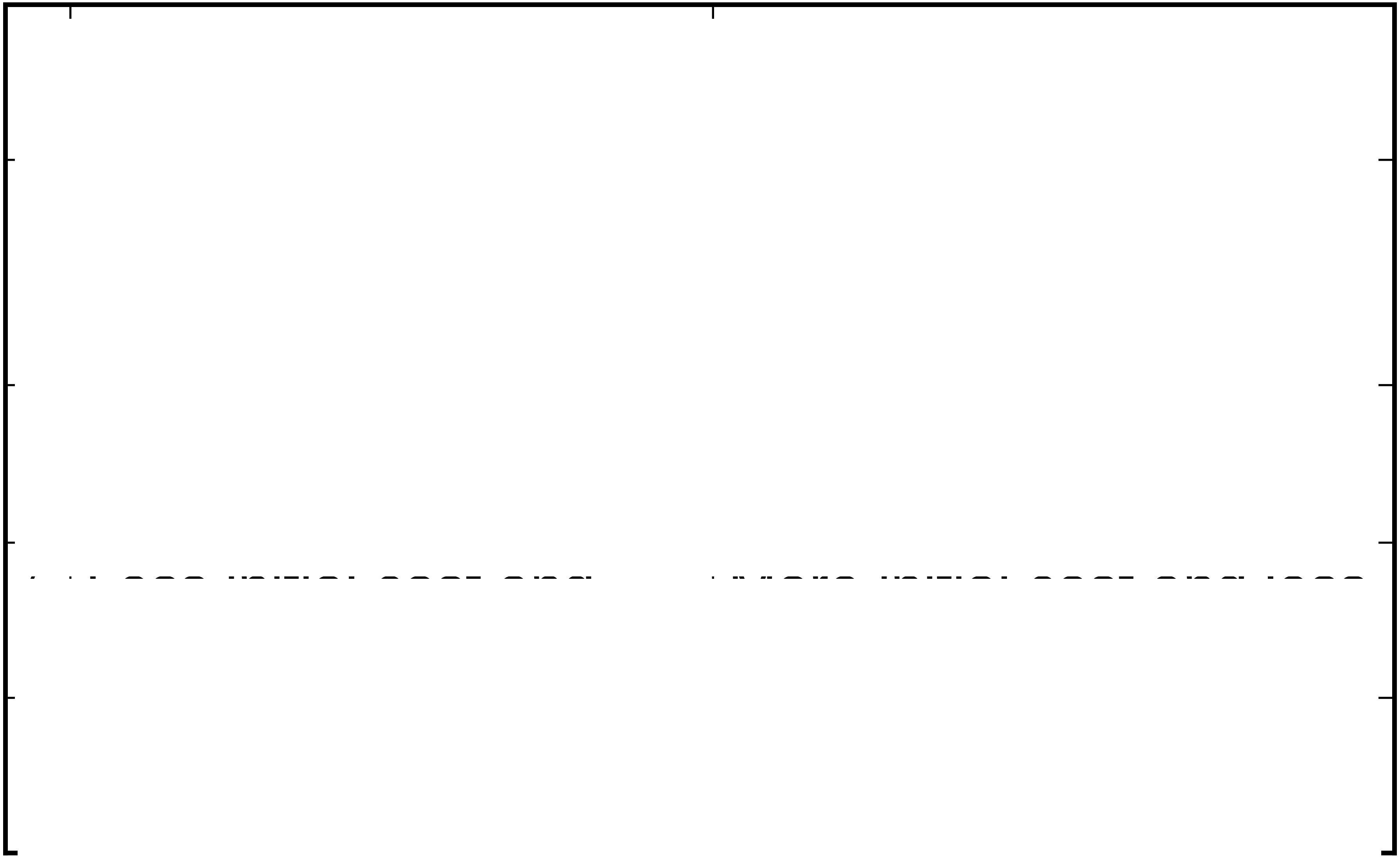
Flywheel is a heavy disc rigidly keyed to the crank shaft

4S I.C. ENGINE ANIMATION

Comparison between Petrol & Diesel Engine

	Petrol engine	Diesel engine
1	It works on Otto cycle.	It works on Diesel cycle.

n

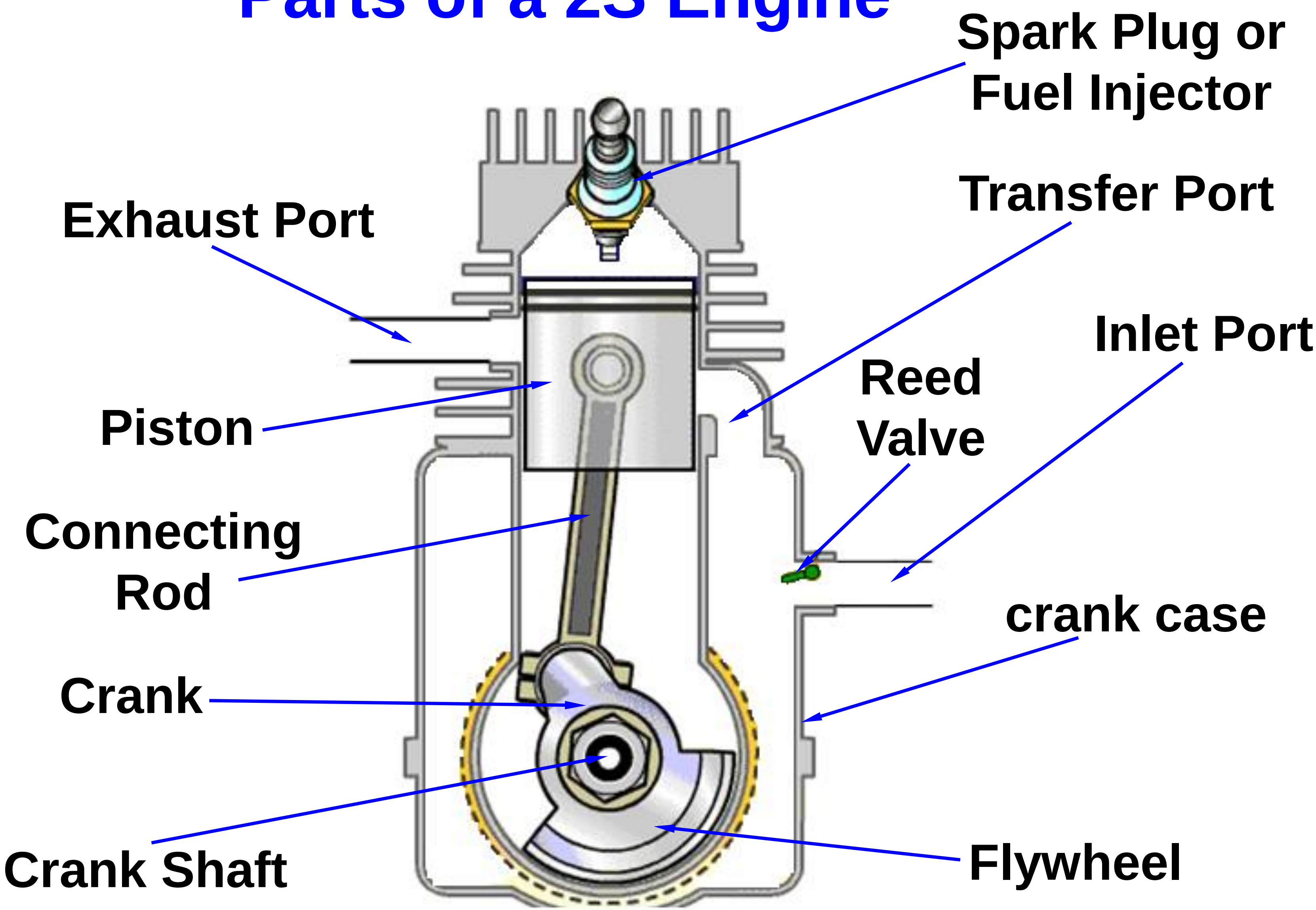


		Difficult to start in cold

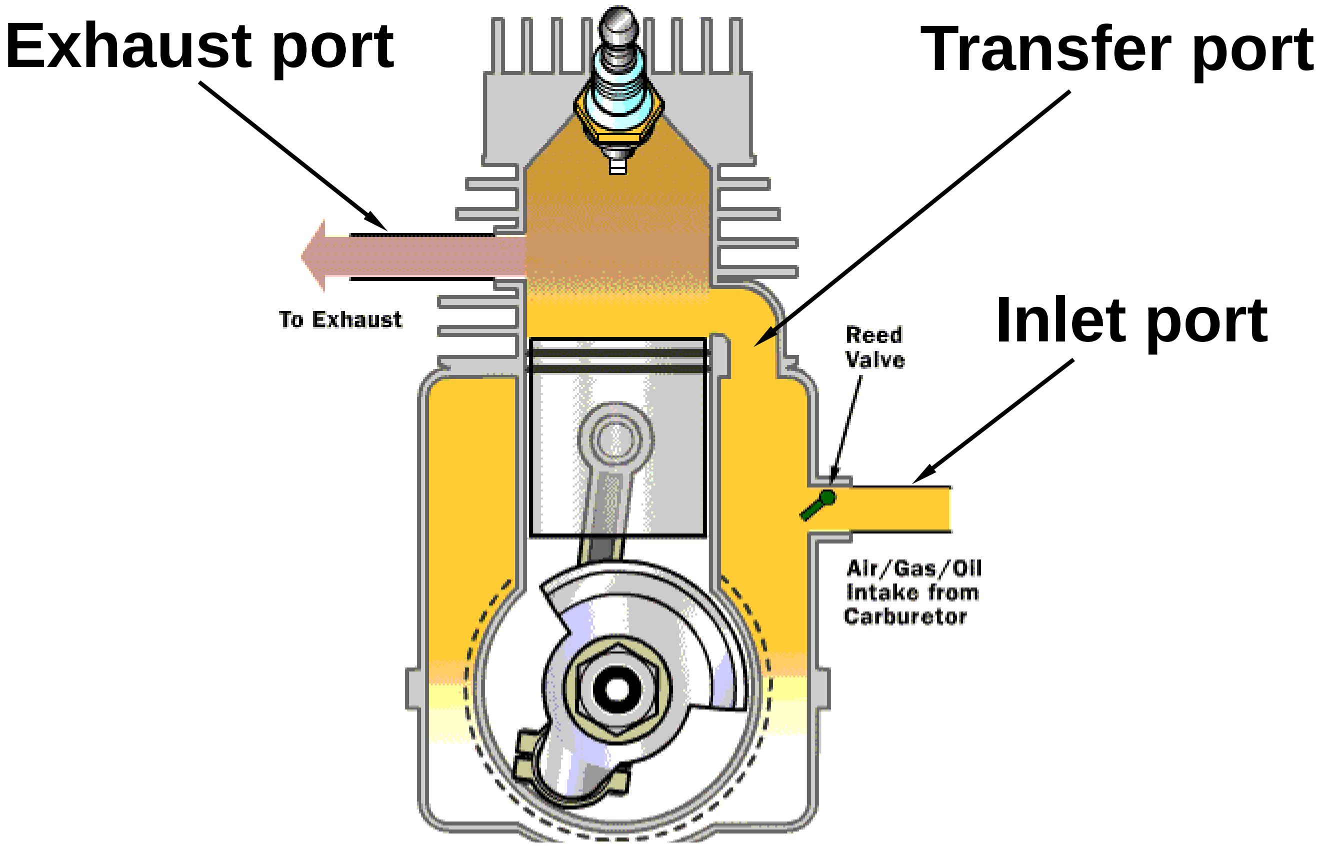
Two Stroke Engine

- In a two stroke engine, one cycle is completed by the ***two strokes*** of the piston.
- Out of the four strokes, the two strokes that are eliminated are, ***suction*** and ***exhaust*** strokes.
- Actually the suction and exhaust processes are performed while the power and compression strokes are in progress.
- In case of the two stroke engines instead of valves, ***ports*** are used.
- Ports in the cylinder liner are opened and closed by the piston motion itself.

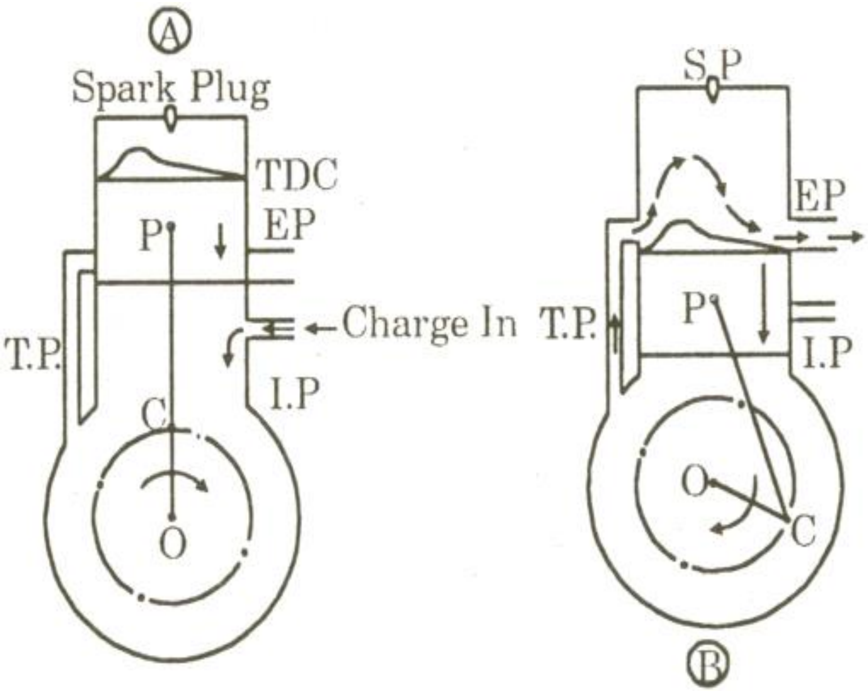
Parts of a 2S Engine



Working of 2S Petrol Engine



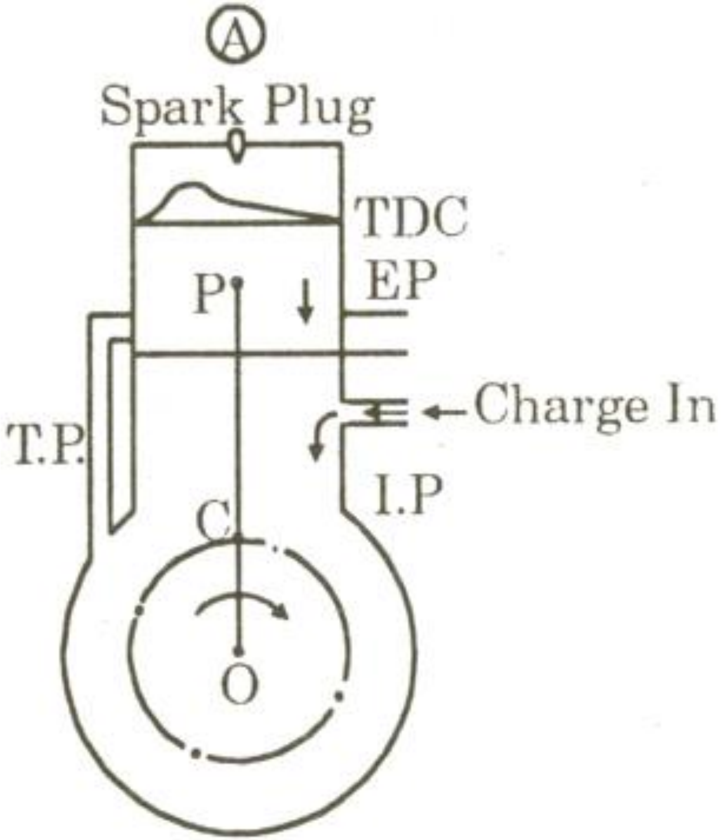
Working of 2S Petrol Engine



First stroke

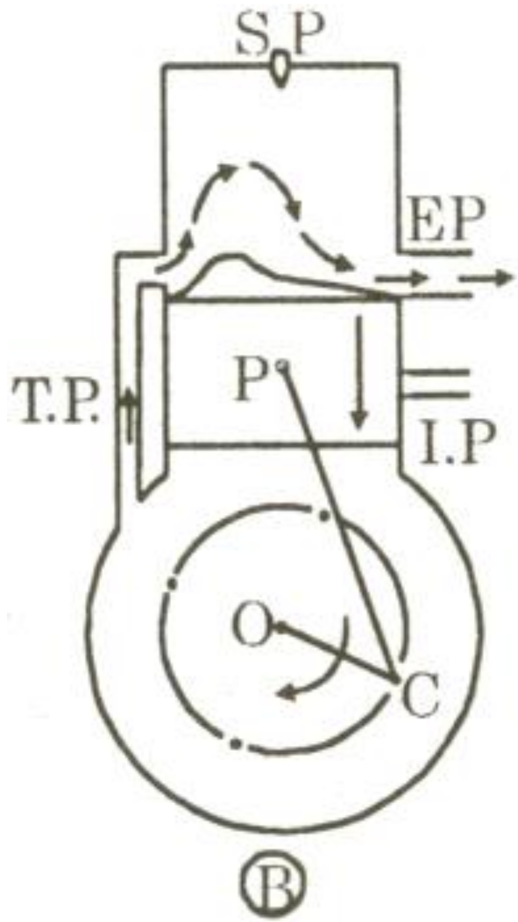
First stroke (Downward)

- As soon as the charge is ignited by the spark plug, the hot gases force the piston to move from TDC to BDC.
- Crankshaft rotates by half a rotation, thus doing the useful work.
- During this stroke the inlet port is covered by the piston and the new charge is compressed in the crank case as shown in the figure.



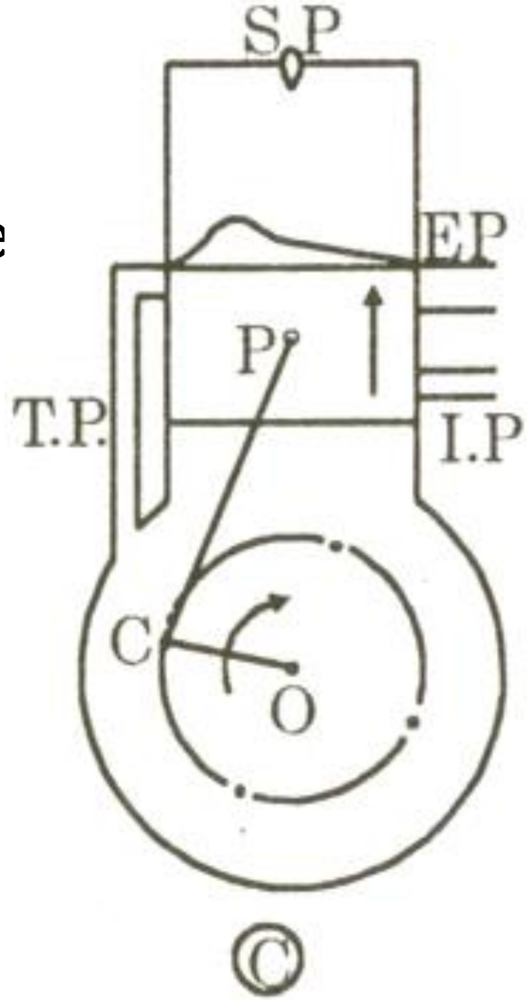
- Further downward movement of the piston ***uncovers first the exhaust port and then the transfer port.***
- The burnt gases escape through the exhaust port.

- As soon as the transfer port opens, the compressed charge from the crankcase flows into the cylinder.
- As the compressed charge enters into the cylinder, it pushes out the exhaust gases from the cylinder.
- The process of removal of exhaust gases by the fresh incoming charge is known as ***scavenging.***

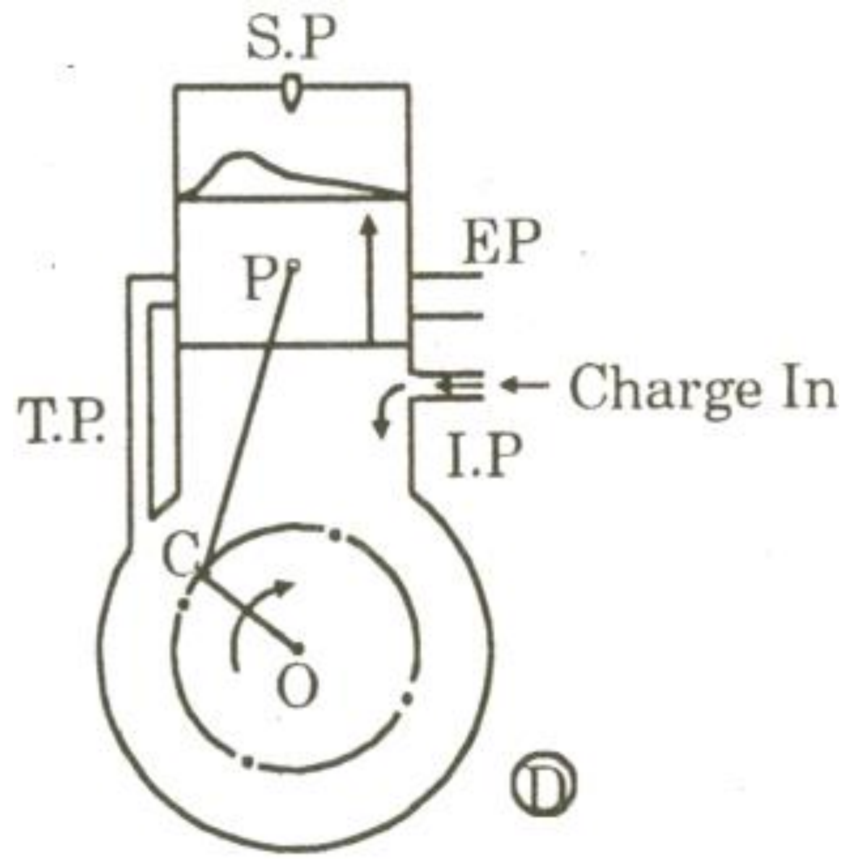


Second stroke: (upward)

- Here the piston moves from BDC to TDC, during which the ***exhaust port and transfer port are covered*** and the charge in the cylinder is compressed.
- Simultaneously, vacuum is created in the crankcase, and a new charge is drawn into the crankcase through the ***uncovered inlet port.***



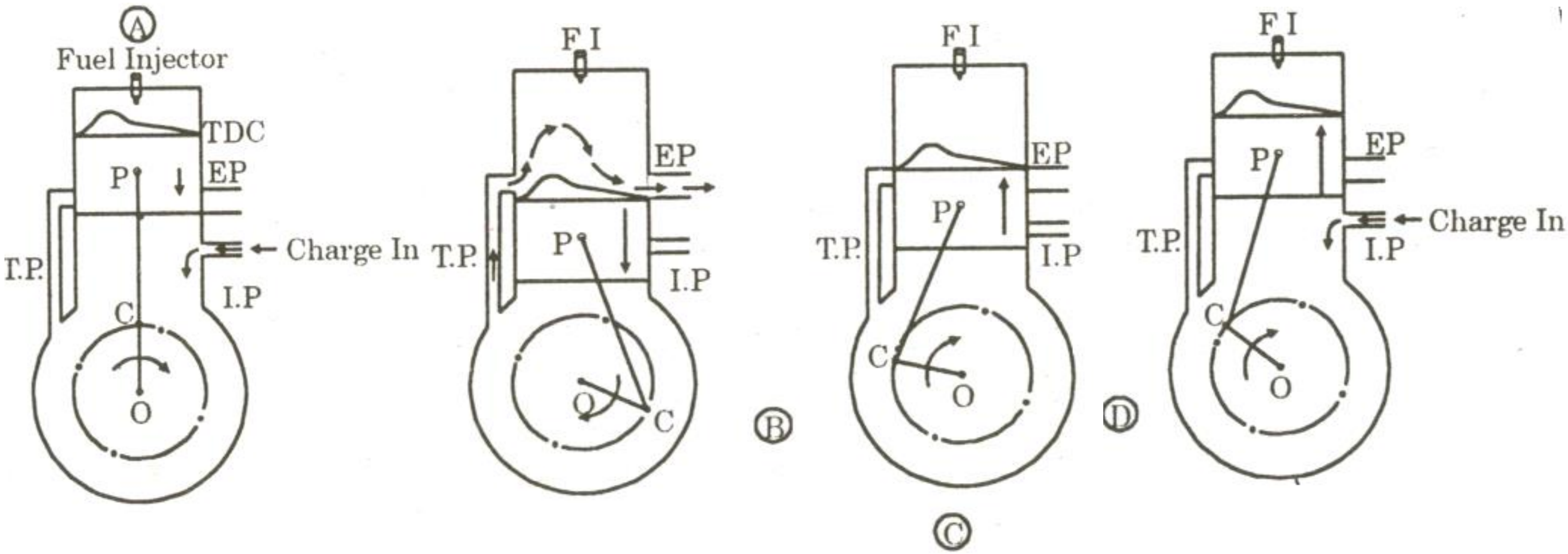
- The compressed charge is ignited in the combustion chamber by a spark provided by the spark plug and the cycle of events is then repeated.



Concluding Remarks on working of 2S Petrol Engine

- This engine requires 2 strokes to complete one working cycle.
- The crank shaft makes one revolution to complete one cycle (half revolution per stroke).
- Power is developed in every revolution of the crankshaft.
- Energy developed during the first (power) stroke is stored in the ***flywheel.*** Energy required to perform the second stroke is provided from the flywheel.
- Smaller flywheel is required as power is developed in every revolution of crank shaft.
- At start of engine, energy required to perform the strokes is provided by ***cranking.***

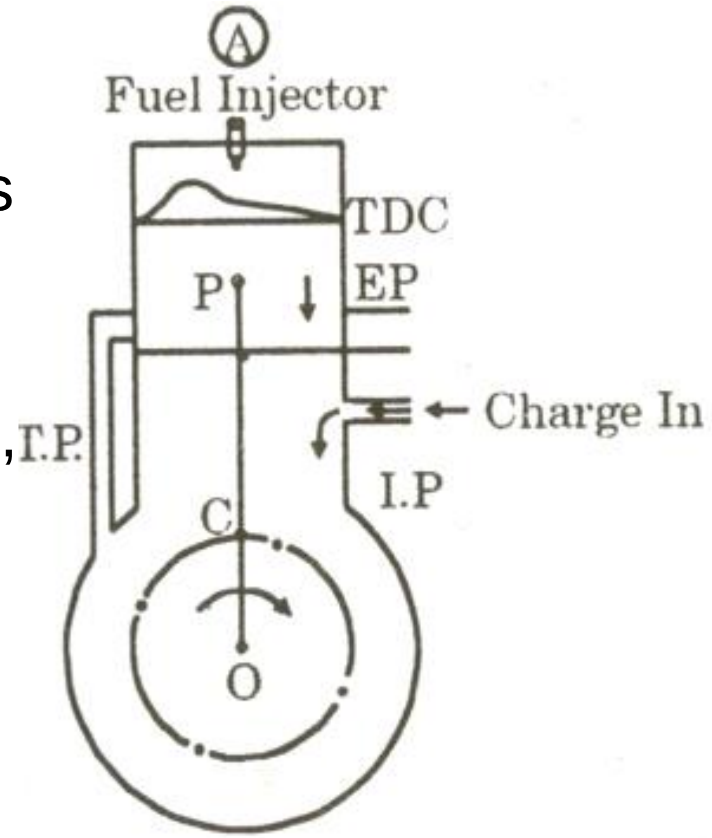
Working of 2S Diesel Engine



First stroke **Second stroke**

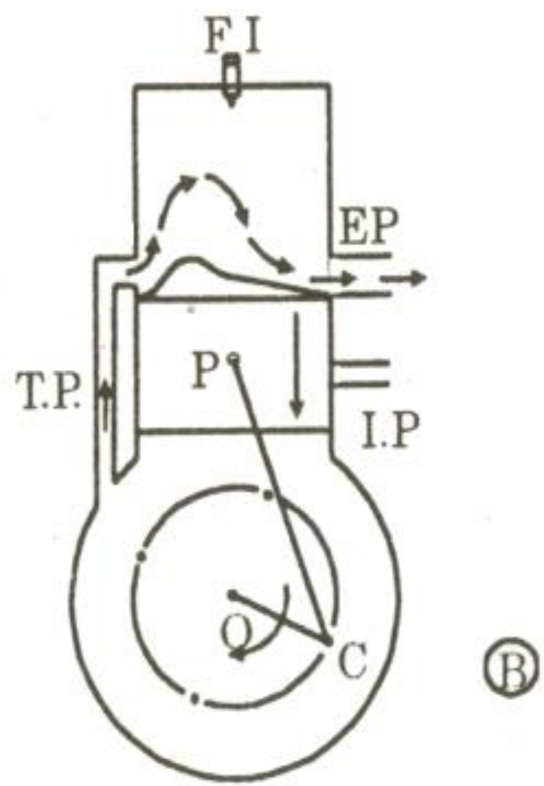
First stroke (Downward)

- When the fuel injector injects the diesel into the hot compressed air, combustion starts and the hot gases force the piston to move from TDC to BDC.
- Crankshaft rotates by half a rotation, thus doing the useful work.
- During this stroke the inlet port is covered by the piston and the new charge [air] is compressed in the crank case as shown in the figure.



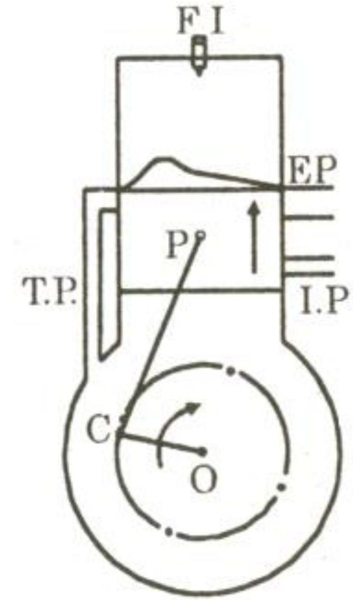
- Further downward movement of the piston ***uncovers first the exhaust port and then the transfer port.***
- The burnt gases escape through the exhaust port.

- As soon as the transfer port opens, the compressed charge from the crankcase flows into the cylinder.
- As the compressed charge enters into the cylinder, it pushes out the exhaust gases from the cylinder.
- The process of removal of exhaust gases by the fresh incoming air is known as ***scavenging.***

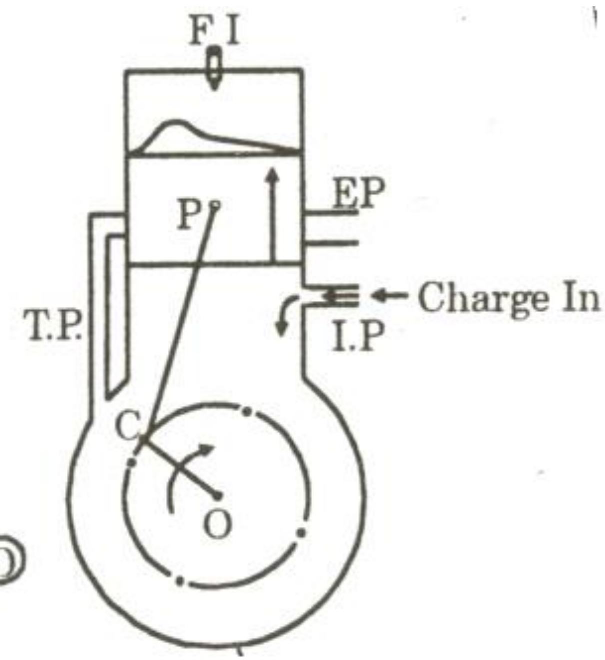


Second stroke: (upward)

- Here the piston moves from BDC to TDC, during which the exhaust port and transfer port are covered and the fresh air in the cylinder is compressed.
- Simultaneously, vacuum is created in the crankcase, and a new charge [air] is drawn into the crankcase through the uncovered inlet port.



(C)



(D)

- At the end of the compression diesel is injected to the compressed air which is at a temperature higher than the self ignition temperature of diesel.
- Hence, the injected diesel auto ignites when it comes in contact with hot air.
- The cycle of events are then repeated.

Comparison between 4S & 2S Engine

	4S Engine	2S Engine
1	One working stroke for	One working stroke for

More output due to full	Less output due to

	It requires lesser	It requires greater cooling

S

Simple Calculations in IC Engines

(1) Mean Effective Pressure (p_m):

- It is the average pressure of the burnt gases acting on the piston during the one complete cycle.
- It's actual value is determined from the actual P-V diagram obtained from a device known as spring indicator.
- It is given by the expression:

$$p_m = \frac{sa}{l} \quad N/m^2$$

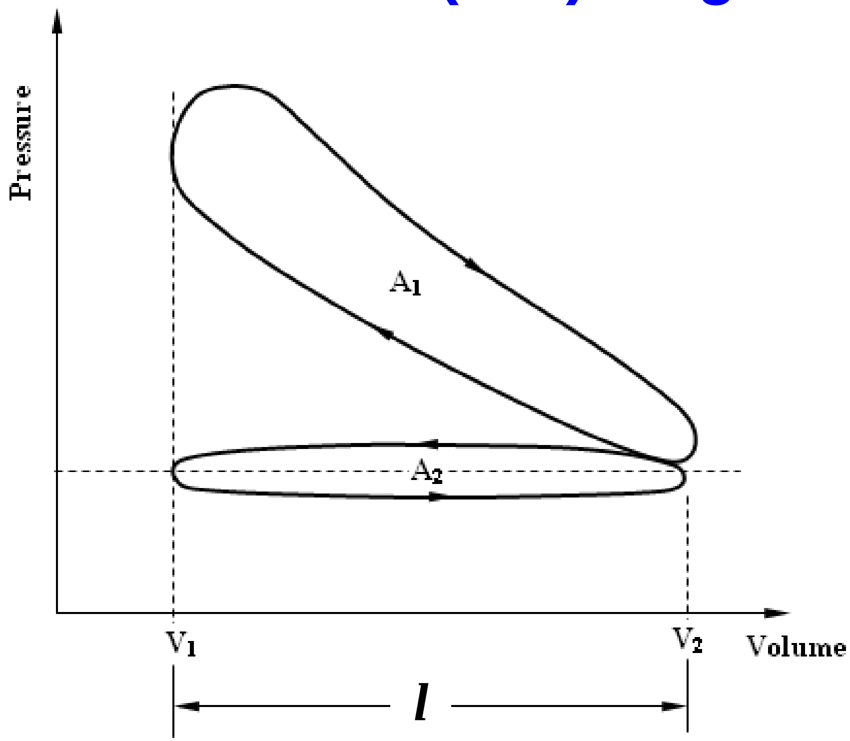
where,

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

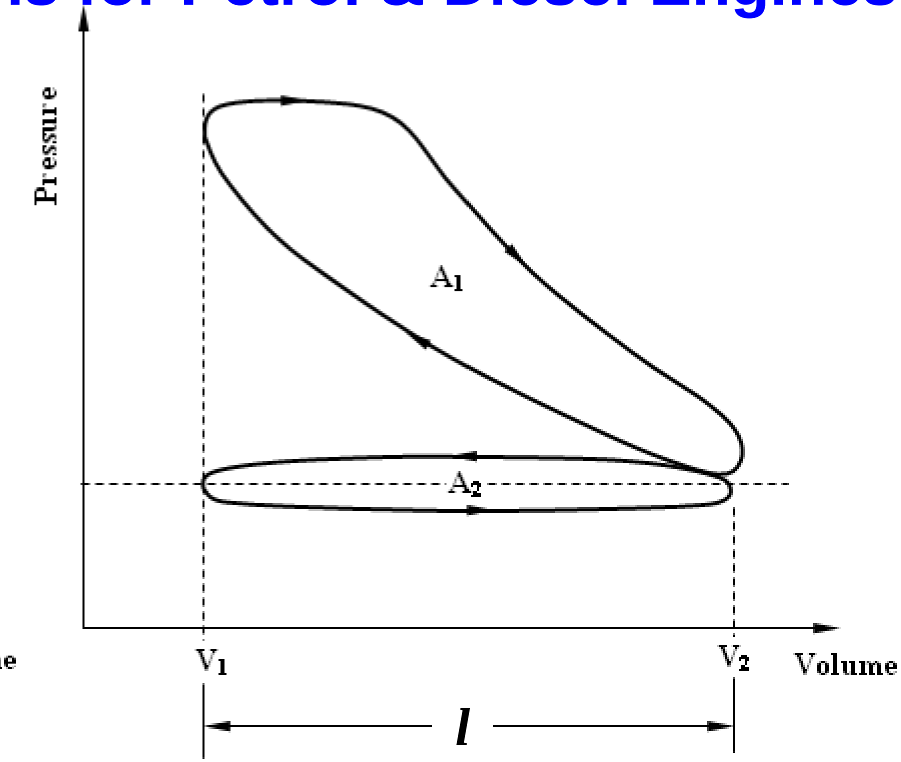
a = Area of the actual indicator diagram, cm^2

l = Base length of the indicator diagram, cm

Actual indicator (P-V) diagrams for Petrol & Diesel Engines



Actual P-V diagram for petrol engine



Actual P-V diagram for diesel engine

A_1 = Positive loop area = the actual work developed

A_2 = Negative loop area = work used to discharge the exhaust gases to the atmosphere

a = Net area = $(A_1 - A_2)$ = Net work done

l = Base length of the indicator diagram

(2) Indicated Power:

Let p_m = Mean Effective pressure, N/m^2

L = Stroke length, m

A = Area of cross section of the cylinder, m^2

N = Speed of the Crank shaft, rpm

n = Number of cycles per minute

$$\left\{\begin{array}{l}\text{Work done}\\\text{by the piston}\\\text{per cycle}\end{array}\right\} = \left\{\begin{array}{l}\text{Mean force}\\\text{acting on}\\\text{the piston}\end{array}\right\} \times \left\{\begin{array}{l}\text{Piston}\\\text{displacement in}\\\text{one power stroke}\end{array}\right\}$$

$$= p_m \times A \times L$$

$$\text{Work done by the piston per minute} = \left\{\text{Work done by the piston per cycle}\right\} \times \left\{\text{Number of cycles per minute}\right\}$$

i.e., Indicated Power (IP) = $p_m \times A \times L \times n$ Nm/min

$$\boxed{\therefore \;\; IP = \frac{p_m L A n}{60} \;\; Nm/\sec}$$

For 4S Engine, n = N/2

For 2S Engine, n = N

Important definitions

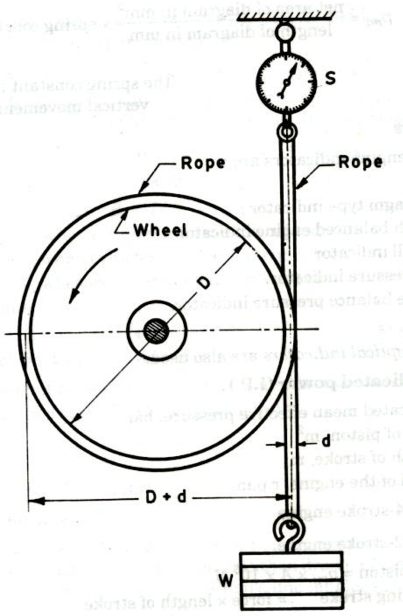
- **Brake Power [B.P]:** It is the power developed by the engine at the output shaft.

$$Brakepower, = \frac{2\pi NT}{60000} kW$$

Where, N = Speed of the crank shaft in rpm.

T =Torque applied on the brake drum due to load “W”, (N-m)

R = Radius of the brake drum (m)



T = W x R kg-m
= 9.81 x W x R N-m

- **Indicated Power [I.P]:** It is the power developed inside the IC engine cylinder

$$Indicated power, = \frac{i \times P_m \times L \times A \times n}{60000} kW$$

Where, n = No. of working cycles/ min.

n = N/2, for 4 stroke engine

= N, for 2 stroke engine

L = Stroke length (m), D = Bore diameter (m)

P_m = Indicated mean effective pressure (N/m^2)

A = Area of the cylinder, $A = \frac{\pi}{4} D^2, m^2$

- **Frictional Power [F.P]:** It is the difference between the indicated power and the brake power.

$$F.P = [I.P - B.P] \quad kW$$

,

- **Mechanical Efficiency [η_{mech}]:** It is the ratio of the brake power and the indicated power.

$$Mechanical efficiency, \eta_{mech} = \frac{B.P}{I.P} \times 100\%$$

- **Brake thermal Efficiency [η_{bth}]:** It is the ratio of the brake power to the heat supplied by the fuel.

$$\eta_{bth} = \frac{B.P \times 3600}{m_f \times C_v} * 100\%$$

- **Indicated thermal Efficiency [η_{ith}]:**
It is the ratio of the indicated power to the heat supplied by the fuel.

$$\eta_{ith} = \frac{I.P \times 3600}{m_f \times C_v} * 100\%$$

Where, m_f = mass of the fuel supplied (kg/hr)
C_V = Calorific Value of the fuel (kJ/kg)

I.C. Engine Numerical

- **Problem 1:** A four-stroke petrol engine, with 40 mm bore and 60 mm stroke was tested under a constant speed of 600 rpm.
- Diameter of belt dynamometer pulley = 1 m.
- Tight side tension in the belt = 800 N
- Slack side tension in the belt = 400 N
- Determine the brake power developed.
- **Solution:**
- Given: D = 40 mm(0.04 m), L = 60 mm(0.06 m), N = 600 rpm, T_1 (W)= 800 N, T_2 (S)= 400 N & D_d=1m.

- $\therefore$ Radius of dynamometer pulley, $R = D_d/2 = 0.5$ m
- $\therefore$ Torque on the pulley $T = (T_1 - T_2) R$

  $= (800 - 400) \times 0.5 =$ **200 N-m.**

$$BrakePower = \frac{2\Pi NT}{60000} kW$$

$= 2\pi \times 600 \times 200 / 60000 =$ **12.566 kW**

- **Problem 2:** The following observations were obtained during a trial on a four stroke diesel engine.
- Cylinder diameter = 25 cm
- Stroke of the Piston = 40 cm
- Crankshaft speed = 250 rpm
- Net load on the brake drum = 700N
- Brake drum diameter = 2 m
- Mean effective pressure = 6 bar
- Diesel oil consumption = 0.0013 Kg/sec
- Specific gravity of diesel = 0.78
- Calorific Value of diesel = 43900 kJ/kg

- **Find: Brake Power (BP), Indicated Power (IP), Frictional Power (FP), Mechanical Efficiency, Brake Thermal Efficiency, Indicated Thermal Efficiency**

- **Given data:**
- D = 25 cm (0.25 m),
- L = 40 mm(0.4 m),
- N = 250 rpm,
- (W-S) Net load =700N,
- D_d=2m.(R_d =1m)
- P_m= 6 x 10^5 N/m^2.
- massflow rate m^o = 0.0013 kg/sec (4.68 kg/hr),
- Calorific Value of diesel = 43,900 kJ/kg

- **Solution:**
- **Brake Power:**

$$BrakePower = \frac{2\Pi NT}{60000} kW$$

- Torque applied $T = (W-S)\,R_d$ N-m
- $= 700 \times 1$
- $= 700$ N-m

$$Brake Power = \frac{2\Pi NT}{60000} kW$$

» **BP = 18.32 kW**

- **To find IP, Indicated Power:**

$$IP = \frac{i\,P_m\,L\,A\,n}{60000}\,kW$$

$$n = \frac{N}{2} = 125 \cdot cycles/\min$$

$$Area(A) = \frac{\Pi D^2}{4}\,m^2$$

$$IP = \frac{i\,P_m\,L\,A\,n}{60000} = 24.54\,kW$$

C. Frictional Power,

FP = IP – BP = 24.54 – 18.326 = **6.217 kW**

d. Mechanical Efficiency:

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

$$\eta_{mech} = 74.67\%$$

e. Brake Thermal Efficiency :

$$\eta_{bth} = \frac{BP \times 3600 \times 100}{m \times C_v}\%$$

$$\eta_{bth} = 32.11\%$$

f. Indicated Thermal Efficiency:

$$\eta_{ith} = \frac{IP \times 3600 \times 100}{m \times C_v}\%$$

$$\eta_{ith} = 43\%$$

Problem 3: The following observations were obtained during a trial on a four stroke diesel engine.

Cylinder diameter = 25 cm
Stroke of the Piston = 40 cm
Crankshaft speed = 250 rpm
Brake load = 70 kg
Brake drum diameter = 2 m
Mean effective pressure = 6 bar
Diesel oil consumption = 100 cc/min
Specific gravity of diesel = 0.78
Calorific Value of diesel = 43900 kJ/kg

- **Find: Brake Power (BP), Indicated Power (IP), Frictional Power (FP), Mechanical Efficiency, Brake Thermal Efficiency, Indicated Thermal Efficiency**

• **Solution:**

• **This problem is same as the previous one, except that the net load is given in kg, and volume flow rate is given.**

Hint:

$\therefore$ (W-S) Net load = 9.81 x 70 = 686.7 N.

• Given specific gravity =0.78

• $\therefore$ Density is = 780 kg/m^3

• To convert volume flow rate in to mass flow rate we have:

Mass flow rate = Volume flow rate X Density.

= (100 x 10^{-6} x 60) x 780

= 4.68 kg / hr.

Answers:

Brake Power = 17.95 kW

Indicated Power= 24.54 kW

Frictional Power = 6.59 kW

Mechanical Efficiency = 73.14 %

Brake Thermal Efficiency =31.45 %

Indicated Thermal Efficiency = 43

Problem 4: The following observations refer to trial on a single cylinder diesel engine. B.P = 75 kW, ηb_{th} = 35%, η_{mech} = 90%, calorific value of oil used = 40000 kJ/kg. Determine IP, FP, Fuel consumption per brake power hour.

Solution:

Given, B.P = 75 kW, η_{bth} = 35%, η_{mech} = 90%, C_v = 40000 kJ/kg.

We know that,

$$\eta_{mech} = \frac{BP}{IP} \times 100\% \qquad \Rightarrow IP = 83.33 kW$$

To find FP,

we have, FP = IP- BP = 8.33 kW

To find fuel consumption per brake power hour. we have

$$\eta_{bth} = \frac{BP \times 3600 \times 100}{m \times C_v} \%$$

$$35 = \frac{75 \times 3600 \times 100}{m \times 40000} \% \quad \Rightarrow m = 19.285 kg/hr$$

But fuel consumption per brake power hour = m/BP

= 19.285 / 75 = **0.257kg/kW-hr**

- **Problem 5:** The following data is collected from a four stroke single cylinder oil engine running at full speed.
- Bore = 200 mm
- Stroke = 280 mm
- Speed = 300 rpm
- Indicated Mean effective pressure = 5.6 bar
- Torque on the brake drum = 250 N-m
- Oil consumed = 4.2 Kg/hr
- Calorific Value of diesel = 41000 KJ/Kg
- Determine:
- Mechanical Efficiency
- Brake Thermal Efficiency
- Indicated Thermal Efficiency

- **Solution:**
- D = 200 mm = 0.2 m,
- L = 280 mm = 0.28 m,
- N = 300 rpm,
- P_m = 5.6 bar,
- T = 250N-m,
- m = 4.2 Kg/hr,
- C_v = 41000 KJ/Kg.
- **Answer:**
- **BP = 7.85 kW.**
- **IP = 12.31 kW**
- **Mech efficiency= 63.74 %**
- **Brake thermal efficiency = 16.41%**
- **Indicated thermal efficiency = 25.73%**

- **Problem 6: A 4 cylinder 4 stroke I.C engine develops an I.P of 50 kW at 25 cycles /second. The stroke of the engine is 90 mm and bore is 0.8 times the stroke.**
- **A) Find the mean effective pressure in each cylinder.**
- **B) If mechanical efficiency is 80%, what effective brake load would be required if the effective brake drum circumference is 1m.**

- **Solution:**
- **I.P = 50 KW,**
- **i = 4,**
- **L = 0.09 m,**
- **D = 0.8 x 0.09 = 0.072m,**
- **η_{mech} = 80%,**
- **n = 25 cycles /second = 1500 cycles/min,**
- **But for a 4 stroke engine = n = N/2.**
- **$\therefore$N = 2 x n = 1500 x 2 = 3000 rpm**
- **We have IP,**

$$IP = \frac{i\,P_m\,L\,A\,n}{60000}\,kW \qquad 50 = \frac{4 \times P_m \times 0.09 \times \frac{\Pi \times (0.072)^2}{4} \times 1500}{60000}\,kW$$

$$\Rightarrow P_m = 13.6 bar$$

- B) to find the effective brake load (W-S) if brake drum circumference is 1m.
- First calculate, BP. Using given mechanical efficiency formula

$$\eta_{mech} = \frac{BP}{IP} \times 100\% \qquad 80 = \frac{BP}{50} \times 100\%$$

$$\Rightarrow BP = 40kW$$

- Now, Substituting the value of BP in the below formula to find 'T' Torque.

$$BrakePower = \frac{2\Pi NT}{60000} kW \qquad \Rightarrow T = 127.32Nm$$

- We have torque $t = (W\text{-}S) \times R_d$
- But circumference of the brake drum
- $= 2\pi R_d = 1$ m.
- $\therefore R_d = 0.159$ m

- $\therefore T = 127.32 = (w\text{-}s) \times 0.159 = 800$ N.

- **Problem 6: The following data refers to twin cylinder four stroke petrol engine.**
- **Cylinder diameter = 200 mm**
- **Stroke of the Piston = 300 mm**
- **Crankshaft speed = 300 rpm**
- **Effective Brake load = 50 kg**
- **Mean circumference of the brake drum = 4 m**
- **Mean effective pressure = 6 bar**
- **Calculate:**
- **Brake Power**
- **Indicated Power**
- **Mechanical Efficiency**

- **Solution:**
- **D = 200 mm = 0.2 m,**
- **L = 300 mm = 0.3 m,**
- **N = 300 rpm,**
- **P_m = 6 bar,**
- **W-S = 50 Kg, (490.5N)**
- **Circumference $2\pi R_d$ = 4m, $\therefore R_d$ = 0.6366m**
- **i = 2**
- **n = N/2 = 150 cycles / min.**

- **Answer:**

- **BP = 9.8 kW**
- **IP = 28.27 kW**
- **Mechanical Efficiency = 34.67%**

- **Problem 7: A four cylinder four stroke petrol engine develops indicated power of 15kW at 1000 rpm. The indicated mean effective pressure is 0.55 MPa. Calculate the bore and stroke of the piston if the length of stroke is 1.5 times the bore.**

- **Solution:**
- **i = 4,**
- **IP = 15 kW, N = 1000 rpm, L = 1.5D,**
- **P_m= 0.55 MPa = 5.5 bar**
- **Since it is four stroke engine**
- **n = N/2 = 500 cycles/min.**

$$Indicated Power(IP) = \frac{i P_m L A n}{60000} \qquad where, A = \frac{\pi}{4} D^2$$

$$15 = \frac{4 \times 5.5 \times 10^5 \times (1.5D) \frac{\Pi D^2}{4} \times 500}{60000}$$

$$\Rightarrow D^3 = 6.945 \times 10^{-4}$$

- **The bore diameter D = 0.0886 m = 88.6 mm**
- **Length of stroke L = 1.5 D**

  = 1.5 x 88.6 = 132.9 mm

Problem 8: The following data refers to a test on a petrol engine: Indicated Power = 40KW, Brake Power = 35KW, Calorific value of fuel =44,000 KJ/kg. Fuel consumption per brake power-hour = 0.3kg. Calculate Brake thermal efficiency.

Solution:

- **Given, IP = 40 kW, BP = 35kW, C_v=44000 kJ/kg. m =0.3 kg / BP-hr.**

To find mass flow rate in kg/hr,

m = 0.3 x BP = 0.3 x 35 = 10.5 kg/hr.

$$Brake thermal efficiency, \eta_{bth} = \frac{BP \times 3600 \times 100}{m \times C_v} \%$$

$$\Rightarrow \eta_{bth} = 27.27\%$$

Problem 9: Calculate the brake power of a twin cylinder four stroke petrol engine, given:

Diameter of brake drum = 600mm

Brake rope diameter = 3 cm

Dead weight = 24kg.

Spring balance reading = 4kg.

Speed of the crankshaft = 7.5 rotation per second

Solution: Given,

W= 24 kg

S= 4 kg

D_d=0.6m (600mm)

D_r =0.03m(3 cm)

Speed = 7.5 rps = 7.5x60=450 rpm.

W-S = 20 kg = 196.2 N

$\therefore$ Effective radius = R = $(D_d + D_r)/2$ =0.315m.

Torque applied = (W-S) x R

= 61.803 Nm.

$$BrakePower = \frac{2\Pi NT}{60000} kW$$

$$\Rightarrow BP = 2.912 kW$$

Problem 10: A test on a single cylinder four-stroke diesel engine gave the following while running on full load. Area of indicator card 300mm^2, length of diagram 40mm, spring constant 1000bar/m, speed 400 rpm, diameter of cylinder 160mm and stroke 200mm. Calculate: Mean effective pressure & Indicated power.

Solution: Given, L = 0.2 m, D = 0.16 m.

Area of indicator diagram a =300 mm^2 =300 x 10^{-6} m^2

Length of indicator diagram (l)= 40 mm = 0.04 m

Spring constant

(S) = 1000 bar / m= 1000x 10^5 N/m^2 /m

Mean effective pressure $P_m = \frac{Sa}{l} N/m^2$

$$\Rightarrow P_m = 7.5 bar$$

$$IP = \frac{i\, P_m\, L\, A\, n}{60000} kW$$

$$\Rightarrow IP = 10.05 kW$$