MODULE II

AIR STANDARD CYCLES

Reversible process: If the system is completely restored back to its initial state after some process. it is called reversible process.

#area under PV diagram use net work done

#area under T-ϕ diagram gives net heat transfer

Assumptions in deriving air standard cycle:

- air is used as working substance
- the gas in engine cylinder is a perfect gas i.e. it obeys gas laws
- all the compressions and expansion process are adiabatic
- there will be low friction during the process
- the cycle is considered a closed one and some air is used to repeat the cycle
- no chemical reactions take place in engine cylinder
- heat is supplied by bringing a hot body in contact with cylinder at proper points and heat is rejected by bringing a cold body in contact with cylinder at proper points

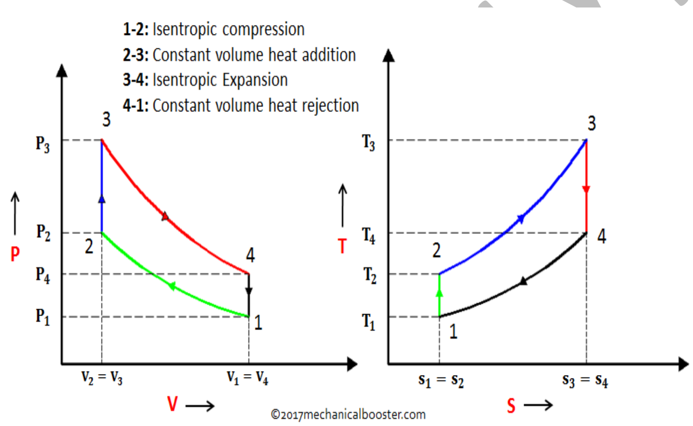
Let the heat received by an engine = Qrec

The heat rejected by an engine = Qrej

Then work done = Qrec – Qrej

Efficiency = output/input = WD/Qrecieved

Otto cycle:



P-V and T-S Diagram of Otto Cycle

process 1-2 (isentropic compression):

- volume decreases from V_1-V_2
- pressure increases from P_1-P_2
- temperature increases from T_1-T_2
- entropy remains constant
- net heat transfer is zero

process 2-3 (isochoric heat addition):

- volume remains constant i.e. V_2=V_3
- pressure increases from P_2-P_3
- temperature increases from T_2-T_3
- entropy increases from ϕ_2-ϕ_3
- heat received = Q_{2-3} = mcVΔT

  = mcV (T_3- T_2) ----------- 1

process 3-4 (isentropic expansion):

- pressure decreases from P_3 – P_4
- volume increases from V_3 – V_4
- temperature decreases from T_3 – T_4
- entropy remains constant
- net heat transfer is zero

process 4-1 (isochoric heat rejection):

- volume remains constant
- pressure decreases from P_4 –P_1
- temperature decreases from T_4 – T_1
- entropy decreases from ϕ_4-ϕ_1
- heat rejection Qrej = mcVΔT

  = mcv (T4-T_1) -------- 2

Derivation of air standard efficiency of Otto cycle:

W/D = Q received – Q rejected

= mcv (T3-T2) – mcv (T4- T1)

= mcv [T3-T2 – T4-T1] --------- 1

Efficiency of Otto cycle, η Otto = work done/heat received

$$= \frac{mcv\,[\,(T3-T2)-(T4-T1)]}{mcv\,(T3-T2)}$$

$$= \frac{[\,(T3-T2)-(T4-T1)]}{(T3-T2)}$$

$$= \frac{(T3-T2)}{(T3-T2)} - \frac{(T4-T1)}{(T3-T2)}$$

$$= 1 - \frac{(T4-T1)}{(T3-T2)} \quad \text{---------} 4$$

>> **consider process 1 – 2** (isentropic compression), for isentropic compression,

$$\boxed{\frac{T2}{T1} = \left[\frac{V1}{V2}\right]^{r}}$$

r → compression ratio

T2 = T1 x r^{r-1} ------ 2

Consider 3 – 4 isentropic expansion,

$$\boxed{\frac{T3}{T4} = \left[\frac{V4}{V3}\right]^{r-1}}$$

$\frac{T3}{T4}$ = r^{r-1}

T3 = T4 x r^{r-1} --------- ❸

We have,

T3 = T4 x r^{r-1} and T2 = T1 x r^{r-1}

so, eqn--❹ »» η Otto = 1- $\frac{(T4-T1)}{(T3-T2)}$

$$= 1 - \frac{(T4-T1)}{\mathrm{T4 \times} r^{r-1} - \mathrm{T1 \times} r^{r-1}}$$

$$= 1 - \frac{(T4-T1)}{r^{r-1} \times (T4-T1)}$$

We have $\boxed{\eta \text{ Otto} = 1 - \frac{1}{r^{r-1}}}$

$\frac{T3}{T4} = r^{r-1}$ (from process 3 – 4)

or $\frac{T2}{T1} = r^{r-1}$ (from process 1 – 2)

i.e. efficiency of Otto cycle = 1 - $\frac{1}{\frac{T3}{T4}}$ or

$= 1 - \frac{1}{\frac{T2}{T1}}$ or

$\boxed{\eta \text{ Otto} = 1 - \frac{T4}{T3}}$ $\boxed{\eta \text{ Otto} = 1 - \frac{T1}{T2}}$

(problems)

Compression ratio(r)

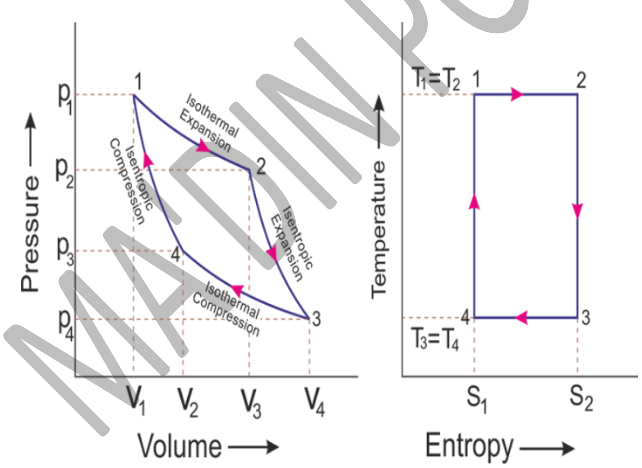
compression ratio = $\frac{total\ volume}{clearance\ volume}$

$= \frac{clearance\ volume + swept\ volume}{clearance\ volume}$

C.R = $\frac{VT}{VC}$

C.R = $\frac{Vs+Vc}{VC}$

carnot cycle:



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

Work done during isentropic process = $\frac{P1V1-P2V2}{\gamma-1}$

process 1 – 2 : (isothermal expansion): a hot body brought to the bottom of cylinder, heat is added at constant temperature.

- volume changes from V_1 to V_2
- pressure changes from P_1 to P_2
- entropy changes from S_1 to S_2
- temperature remains constant

Heat supplied, $Q_{1\text{-}2} = P_1V_1 \log e^{[\frac{V2}{V1}]}$

$= mRT_1 \log r$

$Q_{1-2} = 2.3\ mRT_1 \log r$ ----❶

process 2 – 3 : (isentropic expansion):

The hot body is removed, and a insulating cap (ic) is placed on the bottom of cylinder

- volume changes from V_2 to V_3
- pressure changes from P_2 to P_3
- Temperature changes from T_2 to T_3
- entropy remains constant

Decrease in internal energy = $\frac{P2V2-P3V3}{\gamma-1}$

$= \frac{\mathrm{mrT2-mrT3}}{\gamma-1}$

$= \frac{\mathrm{mr[T2-T3]}}{\gamma-1}$

$= \frac{\mathrm{mr[T1-T3]}}{\gamma-1}$ ------------ ❷

process 3 – 4 : (isothermal compression) :

The insulating cap is removed and the cold body (CB) is brought into the bottom cylinder

The heat is rejected, and volume decreases from V_3 – V_4

- pressure increases from P_3 to P_4
- entropy changes from S_3 to S_4
- temperature remains constant

Heat rejected, $Q_{3\text{-}4} = P_3V_3 \log [\frac{V3}{V4}]$

$= mRT_3 \log r$

$Q_{3-4} = 2.3\ mRT_3 \log r$ ---------❸

process 4 – 1 : (isentropic compression):

The CB is removed and insulating cap is placed on the cylinder, the internal energy increases, and

- volume decreases from V_4 to V_1
- pressure increases from P_4 to P_1
- temperature increases from T_4 to T_1
- entropy remains constant

Increasing internal energy = $\frac{P1V1-P4V4}{\gamma-1}$

$$= \frac{mrT1-mrT4}{\gamma-1}$$

$$= \frac{mr[T1-T4]}{\gamma-1}$$

$$= \frac{mr[T1-T3]}{\gamma-1} \quad \text{---------} ❹$$

The increasing internal energy and, decreasing internal energy are the same, so resultant is zero

Work done = heat supplied – heat rejected

$= 2.3\ mRT_1 \log r - 2.3\ mRT_3 \log r$

WD = $2.3\ mR \log r\ [T_1-T_3]$--------------------------------❺

$$\eta = WD/H.S = \frac{2.3\ mR \log r\ [T_1-T_3]}{2.3\ mRT1 \log r}$$

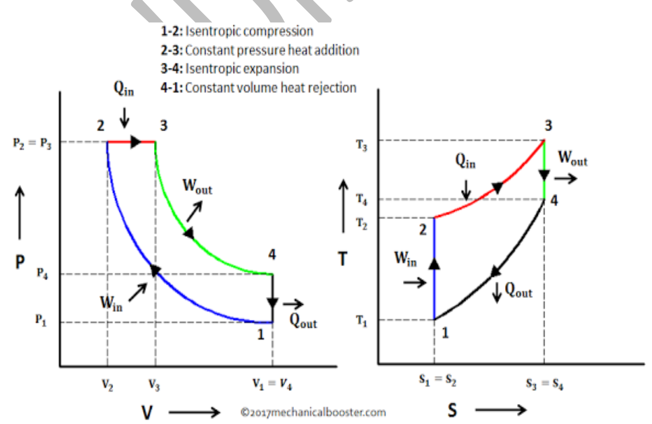
$$\eta = \frac{T_1-T_3}{T_1},$$

$$\eta = 1-\frac{1}{r^{r-1}}$$

$$\boxed{\eta = 1-\frac{T_3}{T_1}} \qquad r = \frac{V2}{V1} = \frac{V3}{V4}$$

i.e . efficiency $=1-\frac{\text{lower temperature}}{\textit{higher temperature}}$

Diesel cycle:



P-V and T-S Diagram of Diesel Cycle

1-2 isobaric heat addition:

- pressure remains constant
- volume increases from V_1 to V_2
- temperature increases from T_1 to T_2
- entropy increases from S_1 to S_2

2-3 isentropic expansion:

- volume increases from V_2 to V_3
- pressure decreases from P_2 to P_3
- entropy remains constant
- temperature decreases from T_2 to T_3

3-4 isochoric heat rejection:

- pressure decreases from P_3 to P_4
- volume remains constant
- temperature decreases from T_3 to T_4
- entropy decreases from S_3 to S_4

4-1 isentropic compression:

- pressure increases from P_4 to P_1
- volume decreases from V_4 to V_1
- temperature increases from T_4 to T_1
- entropy remains constant

$$\eta = 1-\frac{T_3-T_4}{T_2-T_1}$$

$$\eta = 1-\frac{1}{r^{\gamma-1}}\left[\frac{\rho^{r}-1}{r(\rho-1)}\right.$$

r = compression ratio $= \frac{V4}{V1} = \frac{V3}{V1}$

γ= expansion ratio V $= \frac{V3}{V2} = \frac{V4}{V2}$

ρ= cut of ratio $=\frac{V2}{V1}$

WORKING OF IC ENGINE

In a heat engine, the chemical energy of fuel is converted into heat energy, which then is converted to mechanical energy,

Ex: Diesel engine, petrol engine, steam engine, steam turbines, etc....

Heat engine

Internal combn engine

- Fuel is burned Inside the cylinder
- Ex: petrol engine, Diesel engine

External combn engine

- Fuel is burned outside the cylinder.
- Ex: Steam engine, Steam turbine

Sl No	Criteria	Sl No	Types
1	Fuel used	a. b. c.	Petrol engine Diesel engine Gasoline engine
2	Working cycle	a. b. c	Otto engines Diesel engine Dual combustion engine
3	No. Of strokes/ cycles	a. b.	Four stroke engines Two stroke engines
4	Methods of ignition	a. b.	Spark ignition(SI engines) Compression ignition(CI engines)
5	Cooling system	a. b. c	Air cooling engines Water cooling engines Oil cooling engines
6	No. Of cylinders	a. b.	Single cylinder engines Multi cylinder engines
7	**Cylinder arrangement**	a. b. c. d. e.	Horizontal Vertical Radial V- type Opposed piston
8	**Speed**	a. b. c.	Low speed engines(up to 400 rpm) Medium speed engines(400-1000 rpm) High speed engine(above 1000)
9		a. b. c. d. e.	Stationary Automation Aircraft engines Marine engines Loco motive engine

Advantages of IC engine:

1. IC engines are very compact
2. IC engines have high thermal efficiency
3. IC engines do not need auxiliary equipments such as boilers, Furness, etc

Classification of IC engine:

Constructional features:

1. Cylinder:

- Cylinder contains all the reciprocating components

2. Piston:

- Compression takes place at the head of piston
- Cast iron aluminum

3. Gudgeon pin or Wrist pin:

- It connect the piston with connecting rod

4. Connecting rod:

- It connects piston and crankshaft and receives power from piston.

5. Crankshaft:

- It is the main rotating part
- It receives power from connecting rod and transfer it into crank
- Material - forged steel, alloy steel

6. Cam shaft:

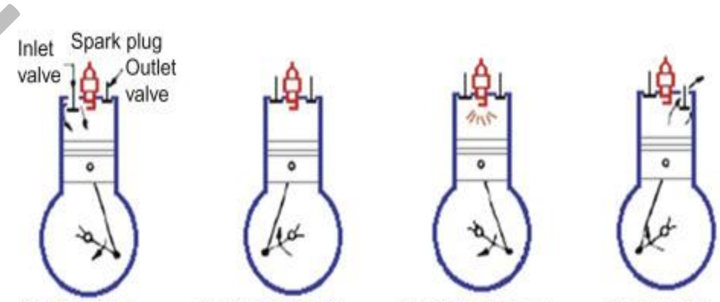
- It controls the opening and closing of valves

7. Valves:

- There are two valves mainly inlet valve and exhaust valve
Inlet valve- nickel chrome steel

Exhaust valves-> silica chrome

Working principle of 4 stroke petrol engine(SI engine):



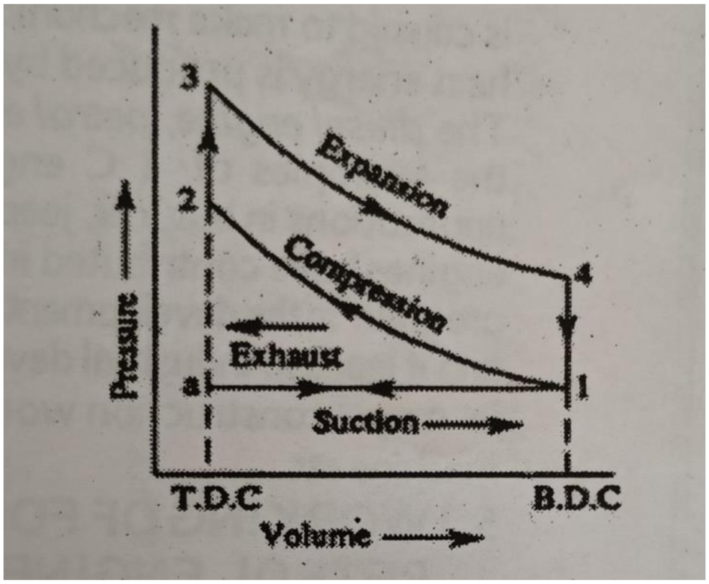
(A) Suction or charging stroke (B) Compression stroke (C) Expansion or working stroke (D) Exhaust stroke

1. Suction stroke
-In suction stroke IV is opened and EV is closed
-piston moves from TDC to BDC, fresh charge of fuel is entered into the cylinder

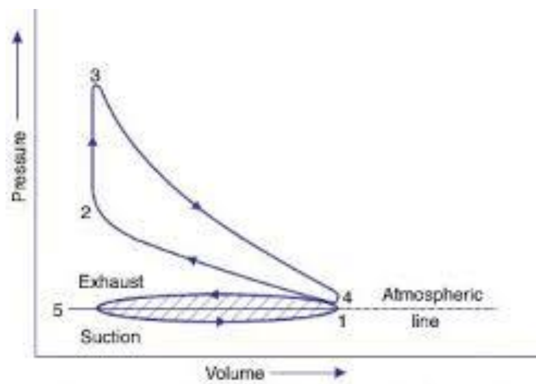
2. Compression stroke:
- Both the valves are closed
- Piston moves from BDC to TDC
-the fuel inside the cylinder is compressed

3. expansion/power/working stroke:
- Both the valves are closed
- At the end of compression stroke spark is produced and the fuel is burned to high temperature and the pressure which pushes the piston from TDC to BDC
-it is the only stroke which produces power

4. Exhaust stroke:
- IV is closed and EV is opened
- Piston moves from BDC to TDC
- pushing the fumes out of the cylinder



THEORETICAL PV DIAGRAM

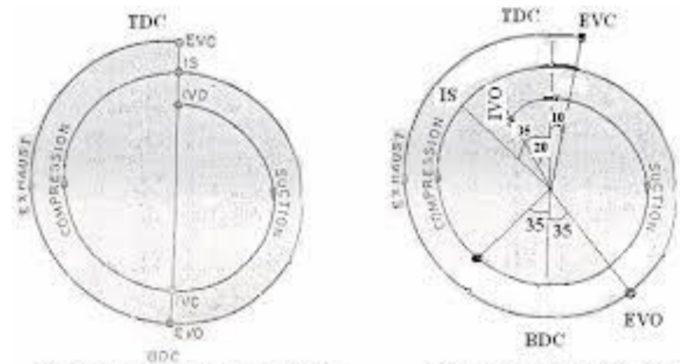


Actual p-V diagram of a four-stroke Otto cycle engine.

ACTUAL PV DIAGRAM

1—2 represents the suction stroke which occurs belong atm. Pressure
2—4 represents compression at point 3 ignition occurs, raising the pressure and temperature to max.
4—5 is the expansion, volume increases and pressure decreases
5--1 represent the exhaust stroke, which occurred above atmospheric pressure

Valve timing diagram:



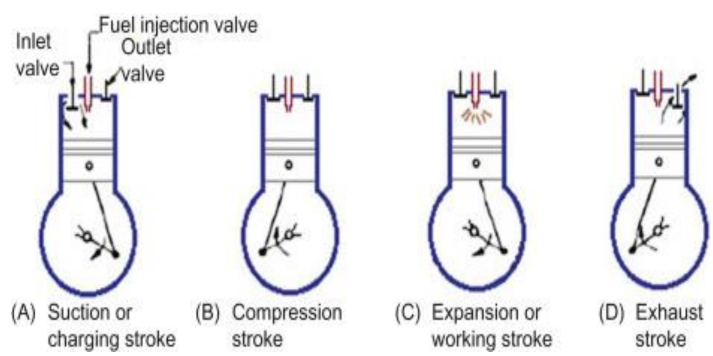
Theoritical Valve timing of a 4 stroke Petrol Engine
Actual Valve Timing for 4 stroke Petrol Engine

EVO – exhaust valve open EVC – exhaust valve closed
IVO – inlet valve is open IVC -- inlet valve is closed

IVO –$10^0 - 20^0$ before TDC
IVC -- 30^0-- 40^0 after BDC
Ignition → 20^0 -- 30^0 before TDC
EVO → $30^0 - 50^0$ before BDC
EVC → 10^0 -- 15^0 after TDC

In actual valve timing diagram the inlet valve is opens $10^0 - 20^0$ before the piston reaches TDC then occurs suction stroke, and inlet valve is closed, 30^0-- 40^0 after BDC and compression stroke occurs, during which the charge is ignited 20^0 -- 30^0 before TDC the next one is power stroke during which exhaust valve is opened about $30^0 - 50^0$ before BDC, during the exhaust stroke the exhaust valve is closed only after 15^0 after TDC.

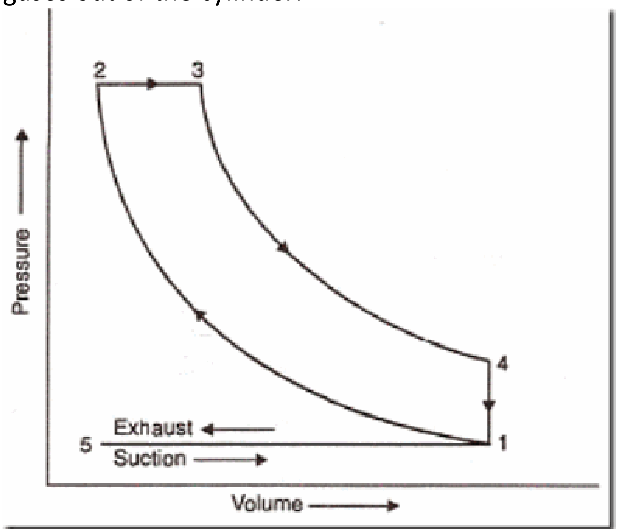
Working principle of 4- stroke Diesel engine:



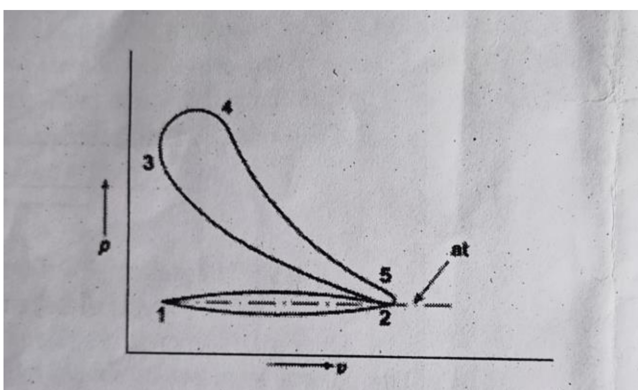
1. Suction stroke:
Piston moves from TDC to BDC, inlet valve is opened, fresh air enters into cylinder.
2. Compression stroke:
Piston moves from BDC to TDC, both the valves are closed, atmosphere air is compressed, at the end of compression fuel (Diesel) is injected through fuel injection in the form of fine spray

3. Power stroke: At the end of compression stroke high temperature and pressure is projected which pushes the piston from TDC to BDC, producing power on the crank, both the valves remains closed.

4. Exhaust Stroke:
During exhaust stroke inlet valve is closed and exhaust valve is opened, piston moves from BDC to TDC, pushing the gases out of the cylinder.



THEORETICAL PV DIAGRAM



ACTUAL PV DIAGRAM

1 – 2 → suction stroke which occurs below atmospheric pressure

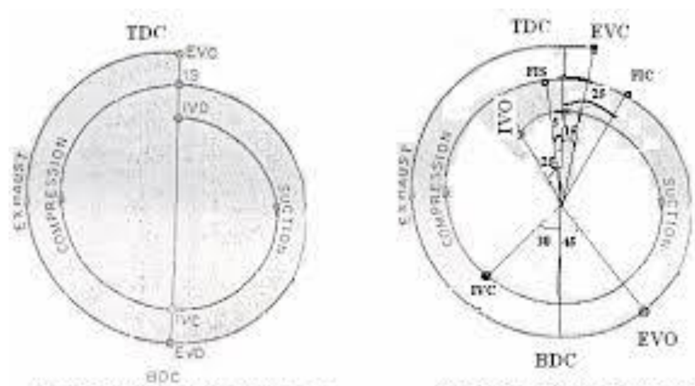
2 – 4 → compression stroke, volume decreases and pressure increases

3 -- > injection of fuel indication

4 – 5 → power stroke, volume increases and pr. Decreases

5 – 1 → exhaust stroke – occurs above atm. Pressure

Valve timing diagram of 4- stroke Diesel engine:



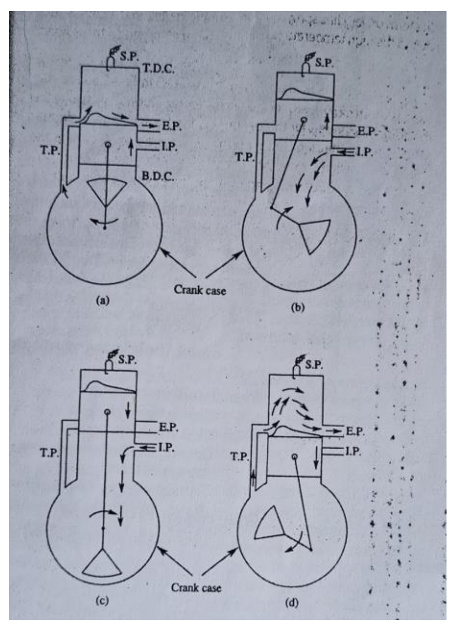
Theoritical Valve timing of a 4 stroke Diesel Engine

Actual Valve Timing for 4 stroke Diesel Engine

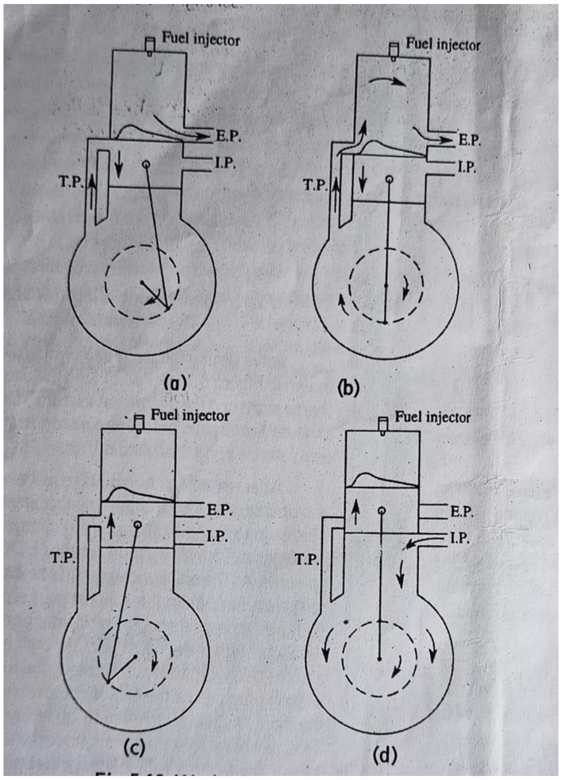
IVO –$10^0 - 20^0$before TDC IVC -- 25^0-- 40^0 after BDC
FVO –$10^0 - 15^0$before TDC FVC -- 15^0-- 20^0 after TDC
EVO –$39^0 - 50^0$before BDC EVC -- 10^0-- 15^0 after TDC

In actual valve timing diagram for diesel engine the inlet vlave is opened $10^0 - 20^0$before TDC , then suction stroke occurs and IV is closed 25^0-- 40^0 after BDC then compression stroke occurs in which fuel valve is opened (FVO) $10^0 - 15^0$before TDC and closed 15^0-- 20^0 after TDC , then power stroke occurs in which exhaust valve is opened $39^0 - 50^0$before BDC. The next one is exhaust stroke in which exhaust valve is closed 10^0-- 15^0 after TDC.

Working of Two stroke engine(petrol/ Diesel):



TWO STROKE PETROL ENGINE



TWO STROKE DIESEL ENGINE

In two stroke engine the cycle is completed in 2 stroke , i.e. one revolution of the crankshaft

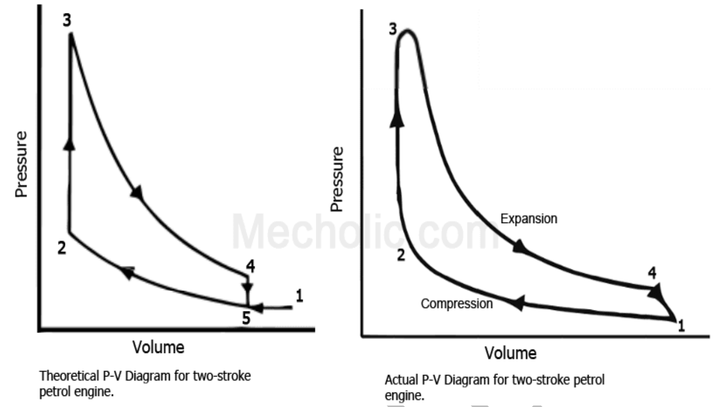
<u>1st stroke (suction + compression):</u>

- Piston moves from BDC to TDC, so pressure inside the crank case decreases and fresh charge (air fuel) in case of petrol engine air only, in case of diesel engine fresh charge enters to the crank case through the inlet port , and both the transfer port and exhaust port is closed.
- The piston compresses previously available charge in cylinder. At the end of the compression charge is ignited in SI engine by spark plug of fuel is injected to compressed air in case of CI engine.

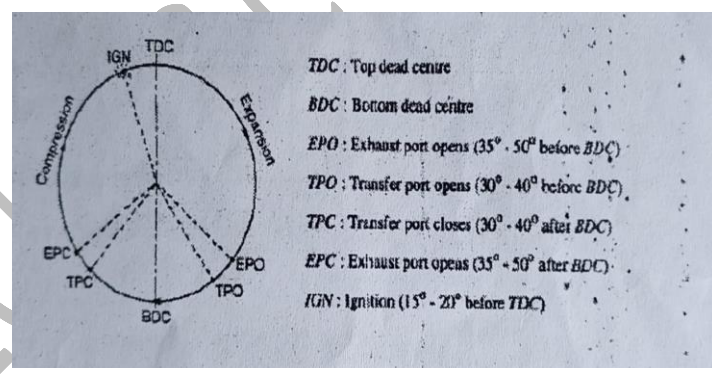
<u>2nd stroke (power+ Exhaust):</u>

- Piston moves from TDC to BDC, inlet port is closed, both the transmission port and exhaust port are opened, so the fresh charge in the crank case moves upwards to the cylinder through transfer port
- The piston feed is slightly curved and the charge entering into the cylinder guides a swirl motion and pushes burnt gases out of the cylinder through exhaust port and the cycle repeats.

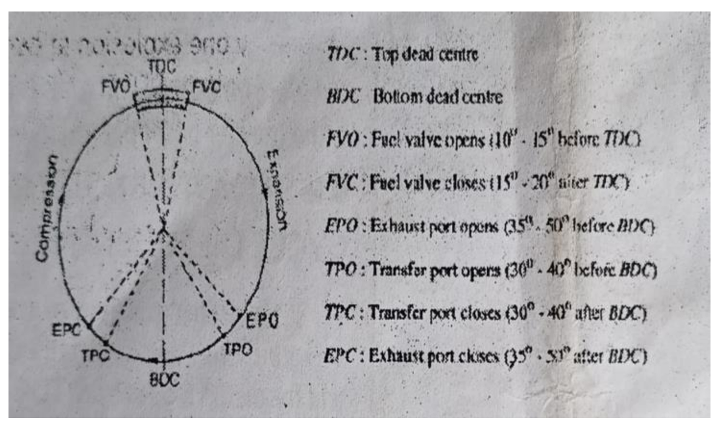
Pv diagram of 2 stroke petrol engine:



Valve timing diagram of 2 stroke petrol engine



Valve timing diagram of 2 stroke Diesel engine



Comparison b/w petrol and Diesel engine(SI Vs CI):

Petrol engine	Diesel engine
- Charge contains air+ fuel mixtures	- Charge contains air only
- It uses carburettor	- Fuel injector is used
- Spark plug is used to ignite fuel	- Due to very high compression of air fuel gets to automatically burned
- Compression ratio is less as compared to CI engine (6:1 to 9:1)	- Compression ratio is high (12-1 to 22:1)
- It is works on Otto cycle.	- Works on diesel cycle
- Initial cost is less	- Initial cost is high
- Easy and quick starting	- Starting is not quick
- For a given output SI engine is lighter in weight.	- Due to high compression ratio, it is heavier.

Comparison b/w 2stroke and 4stroke engine:

2 stroke engine	4 stroke engine
Cycle is completed in 2 stroke of piston or one revolution of crankshaft	Cycle is completed 4 stroke of piston (2 revolution of crankshaft)
Twice as many working stroke per minute as compared to 4 stroke engine	½ of the No. Of working stroke per minutes as compared to 2 stroke engine
Lighter flywheel is required	Heavier flywheel is required
Scavenging of exhaust gases is low	Scavenging of exhaust gases is more effective
Fuel banned is less and hence less output	More fuel burned and higher output
Thermal efficiency is less	Thermal efficiency is high
Generally used by SI engine(petrol and gas)	Generally used by CI engine
More noise	Less noise
Generally used in light vehicles Ex: motor cycles,3 wheelers	Generally used in cars, jeeps, aeroplanes etc..

Scavenging:

It is the process of pushing the burned gases out of the cylinder is called scavenging.