INTERNAL COMBUSTION ENGINES & GAS TURBINES

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2. Comparison between External Combustion engine & Internal Combustion engine
3. Classification of IC engine
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INTRODUCTION

Any type of engine or machine which drives heat energy from the combustion of fuel or any other source & convert this energy in to mechanical work is termed as heat engine. Heat engines may be classified in to two main types as follow

(a) External Combustion Engine

(b) Internal Combustion Engines

In external combustion engines, combustion of fuel takes place outside the cylinder as in case of steam engines where the heat of combustion is employed to generate steam which is used to move a piston in a cylinder. other examples of external combustion engines are:-

Hot air engines, steam turbines & closed cycle gas turbines & applications are:-

Driving Locomotives, ships, generation of electric power etc

Whereas, in IC (Internal Combustion) engines, combustion of the fuel with oxygen of air occurs with in the cylinder of the engine. The IC engines using lighter liquid fuel or spirit known as petrol engines & those using heavier liquid fuel known as oil compression ignition or diesel engines.

After studying this chaper, we shall be able to understand about IC engines, their parts & functions, basic cycles, their working (SI & CI engines), valve timing diagrams of IC engines, indicator diagrams, comparison of 2-stroke & 4-stroke engines, difference between SI & CI engines, Gas turbines etc.

2. Comparison between External combustion engine & I.C. engine

The external combustion engines claim the following advantages over internal combustion engines:

1. Starting torque is generally high.
2. Because of external combustion of fuel, cheaper fuels can be used.
3. These units are self-starting with the working fluid whereas in case of internal combustion engines, some additional equipment or device is used for starting the engines.

I.C. engines (Reciprocating type) offers the following advantages over external combustion engines.

1. Overall efficiency is high.
2. Greater mechanical simplicity.
3. Weight to power ratio is generally low.
4. Generally lower initial cost.
5. Easy starting from cold conditions.
6. These units are compact & thus require less space.

Development of I.C. engines:

Otto gas Engine developed by Dr. Otto in 1879 & Diesel engine began about 1883 by Rudolf Diesel.

3. Classification of I.C. engines

1. According to cycle of operation.
   (i) Two stroke cycle engines
   (ii) Four stroke cycle engines

2. According to cycle of combustion
(i) Otto cycle
(ii) Diesel cycle
(iii) Dual cycle
3. According to arrangement of cylinder
(i) Horizontal engine (ii) Vertical engine
(iii) V-type engine (iv) Radial engine
4. According to fuel used
(i) Oil engine (Diesel engine)
(ii) Petrol engine
(iii) CNG
(IV) LPG
5. According to method of ignition:
(i) Spark ignition engine
(ii) Compression ignition engine
6. According to speed of the engine
(i) Low speed engine
(ii) Medium speed engine
(iii) High speed engine
7. According to method of cooling the cylinder
(i) Air-cooled engine
(ii) Water-cooled engine
8. According to number of cylinders
(i) Single cylinder engine
(ii) Multicylinder engine
9. According to valve arrangement
(i) Over-head valve engine

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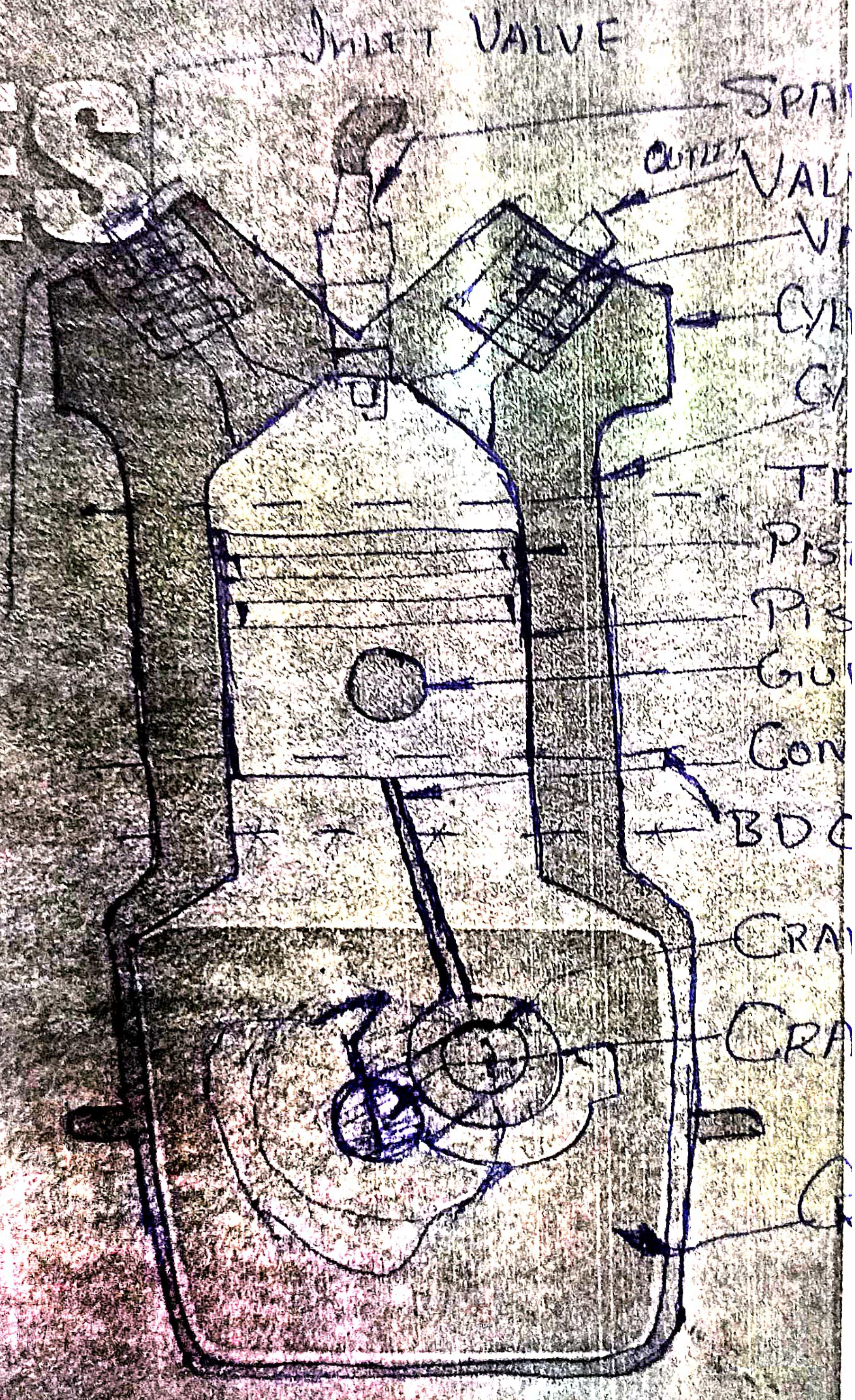


Fig 2

(ii) L-head type engine
(iii) T-head type engine
(iv) F-head type engine

10. According to their use:
(i) Stationary engine.
(ii) Portable engine.
(iii) Marine engine
(iv) Automobile engine
(v) Aero engine etc.

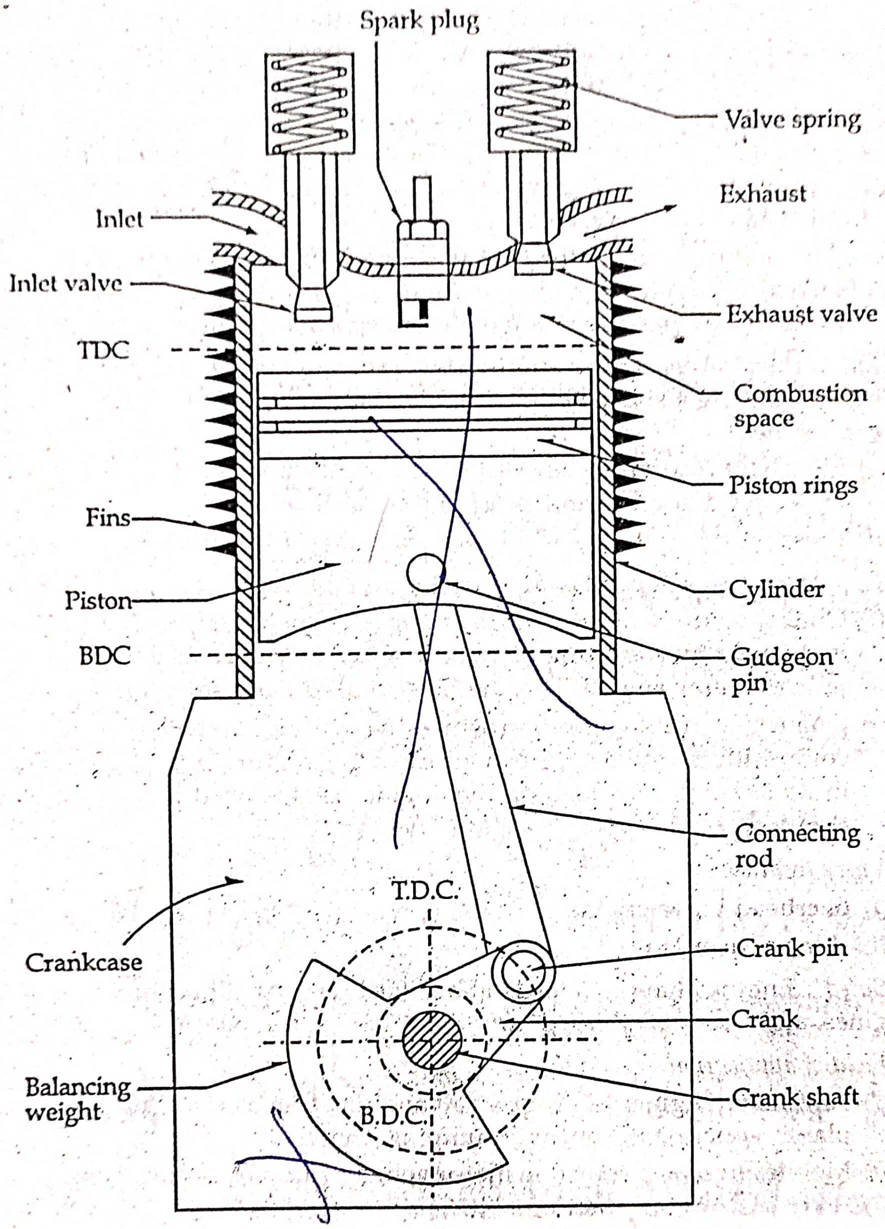
11. According to lubrication system used
(i) Mist lubrication system
(ii) Splash lubrication system
(iii) Pressure lubrication system.

12. According to method of governing
(i) Quality governed engine (Diesel engine)
(ii) Quantity governed engine (Petrol engine)

4. ENGINE PARTS & THEIR FUNCTIONS - (REFER FIG 2)

A. Parts common to both petrol & diesel engine:

1. Cylinder
2. Cylinder head
3. Piston
4. Piston rings
5. Gudgeon pin
6. Connecting rod
7. Crankshaft
8. Crank
9. Engine bearing
10. Crankcase
11. Flywheel
12. Governor
13. Valve & Valve operating mechanism.



Spark plug
Valve spring
Exhaust
Inlet
Inlet valve
Exhaust valve
TDC
Combustion space
Piston rings
Fins
Cylinder
Piston
Gudgeon pin
BDC
Connecting rod
T.D.C.
Crankcase
Crank pin
Crank
Balancing weight
Crank shaft
B.D.C.

B. Parts for Petrol engines only

1. Spark Plug
2. Carburettor

C. Parts for Diesel engines only

1. Fuel injector or nozzle
2. Fuel pump.

A 1. Cylinder :- The inner diameter of cylinder is known as bore. It is the part in which piston reciprocates & combustion of fuel take place. Its volume is divided in to clearance volume & swept volume. It is generally made up of cast iron. It can be air-cooled or water-cooled.

2. Cylinder head :- The cylinder head closes one end of cylinder & it is bolted at the top in case of vertical cylinder. It contains inlet & outlet valve seats. It also consists of the space for injector in case of diesel engine & spark plug in case of petrol engine. It is tightly fitted over cylinder along with gaskets or packings. It is also made up of cast iron.

3. Piston :- (Refer fig 3) Piston forms the first link in transmitting the gas forces to the output shaft. It is a cylindrical component

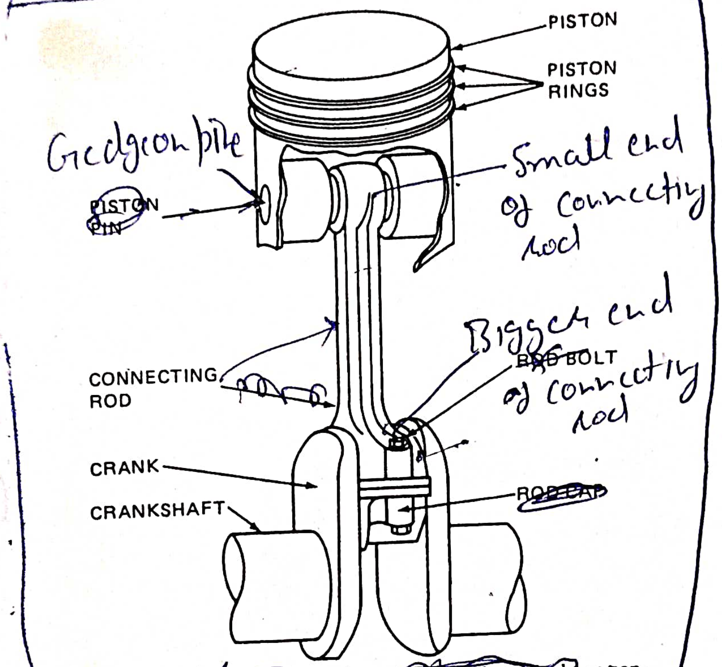


Fig. 11-7 Piston-and-connecting-rod assembly attached to a connecting-rod journal on the crankshaft. The piston is partly cut away to show how the piston pin attaches the piston to the connecting rod.

2 Piston with rings, Connecting rod, crankshaft & crank

Fig. 3

fitted in to the cylinder. It provides a perfectly gas-tight space with the piston-rings & the lubricant.

Pistons are made-up of alluminium alloy, because of its lightness & high strength.

4. Piston rings :- The functions of piston rings are to confine the gases in the combustion chamber & to provide space for lubricants also. The piston rings are provided in the slots of outside the cylinder. Piston rings are generally made of cast iron which may be rectangular or square in cross-section & not affected by working heat.

5. Gudgeon pin - It is also known as piston pin or wrist pin. It forms the link between the small end of the connecting rod & the piston.

6. Connecting rod :- It interconnects the piston & the crankshaft & transmits the gas forces from the piston to the crankshaft. The two ends of the connecting rod are called as small end & big end. The connection at the small end is made by gudgeon pin. And the big end connected to the crankshaft by crank pin. The connecting rod is generally of I-section, made-up of nickle-chrome steels.

7. Crankshaft :- It converts the reciprocating motion of the piston in to useful rotary motion of the output shaft. The crankshaft mounts on the bearings & contain crank.

8. Crank : Crank is part of the crank shaft. The connecting rod's bigger end connected to the crank, hence known as crank end. Crank is made eccentric on the crankshaft so that the reciprocatory motion of piston is converted in to rotary motion of crank shaft with the help of connecting rod.

9. Engine Bearings :- The various rotary parts like crankshaft, piston pins are supported by bearings.

10. Crank case :- The crankshaft is enclosed in crank case which also act as an lubricating oil sump.

11. Flywheel :- In order to achieve a uniform torque, an inertia mass in the form of a wheel is attached to the crankshaft which is known as flywheel. ~~The net~~

12. Governor :- It is used to regulate the supply of fuel, or mixture according to the load requirement so that at different load almost a constant speed is obtained.

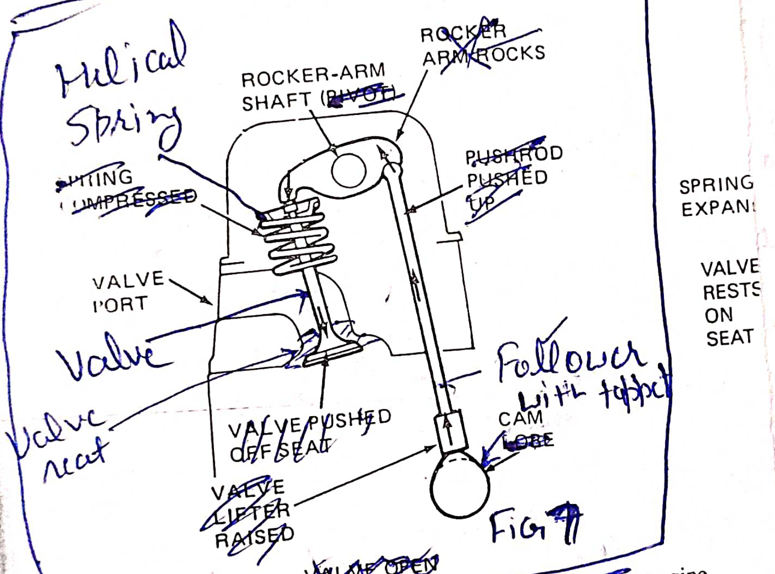


Fig. 14-3 Operation of the valve train in an overhead-valve engine.

VALVE & VALVE MECHANISM

13. VALVES & VALVE OPERATING MECHANISM. The (Refer fig. 7)

valves are situated at the cylinder head. Inlet valves gives a passage to the air-fuel mixture to enter in to cylinder at suction stroke. And exhaust valve gives a passage to the product of combustion escape in to atmosphere at the time of exhaust stroke.

Valves & its operating mechanism consist of following parts.

(a) Camshaft
(b) Cams
(c) Followers or push rod with tappet
(d) Rocker arm with shaft
(e) Helical spring
(f) Valves

→ ~~The camshaft & cam control the opening & closing of the two valves with the help of associated parts.~~ Cams are designed in such a way to open the valves at the correct timing & to keep them open for necessary duration. The camshaft is driven by the crankshaft through timing gears.

The camshaft & cams control the opening & closing of two valves with the help of associated parts like push rod with tappet, rocker arm with shaft, helical spring, valves etc.

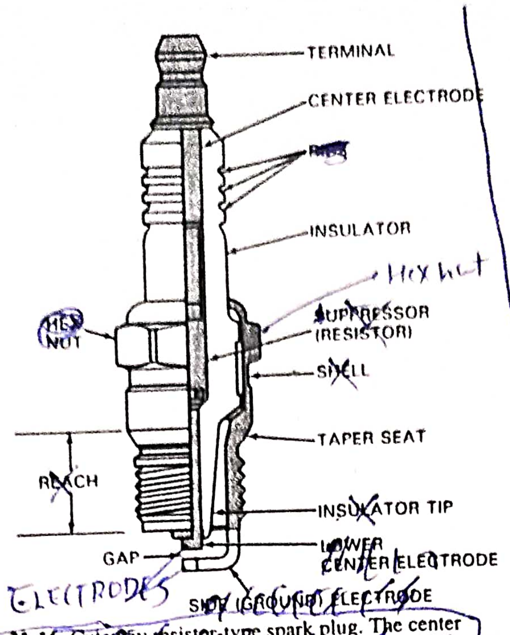


Fig. 31-16 Cutaway resistor-type spark plug. The center electrode is insulated. The side electrode is grounded through the engine. (*AC Spark Plug Division of General Motors Corporation*)

SPARK PLUG
FIG-4

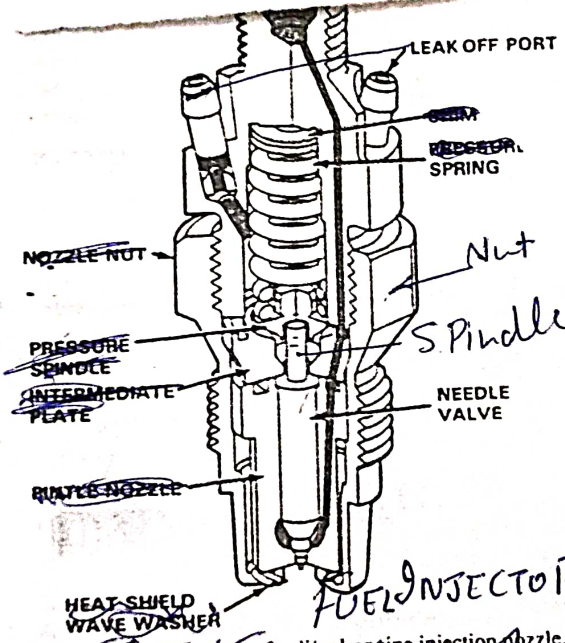
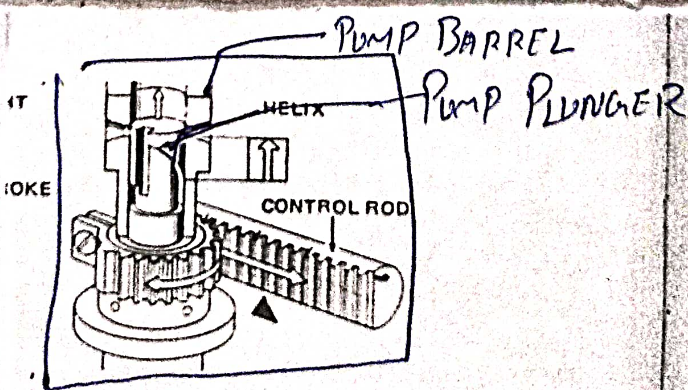


Fig. 23-16 Construction of a diesel-engine injection nozzle. (*Chevrolet Division of General Motors Corporation*)

FIG-5

The fuel for each



FUEL PUMP
Fig. 6

(B) Parts for petrol engine only

Spark plug:- The function of the spark plug is to provide a gap in combustion chamber for the discharge of a high potential electric pulse that will ignite the air-fuel mixture at the desired point in the cycle. (Refer fig. 4)

Carburettor :- The function of carburettor is to make combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder. ~~carburettor~~

(C) Parts for Diesel engine only

1. Fuel injector ~~or nozzle~~ - Its function is to inject the fuel in to the cylinder at the end of compression stroke at very high pressure. During the process of injection, fuel is broken in to a fine spray of very small droplets. These droplets vaporize due to heat transfer from the compressed air & form a fuel-air mixture. Due to continued heat transfer from hot air to the fuel, the temperature reaches a value higher than its self ignition temperature. This causes the fuel to ignite spontaneously initiating the combustion process. (Fig 5)

2. Fuel pump :- Its function is to pump the fuel from fuel tank to ~~cylinder~~ fuel injector at the beginning of Power stroke. (Ref Fig 6)

1. Definitions & Concepts regarding IC engines

REFER Fig 1.

Bore :- The inner diameter of the cylinder is called as bore.

Stroke :- The linear distance between two limiting positions along the axis of cylinder is known as stroke as shown in fig 1

Top Dead Centre (T.D.C) :- It is the upper limit of piston in the cylinder where it can reach is known as "Top dead centre". In case of horizontal engines, this is known as (IDC) inner dead centre

Bottom Dead Centre (BDC) :- It is the lower limit of piston in the cylinder where it can reach is known as bottom dead centre (BDC). In case of horizontal engines it is called outer dead centre. (ODC)

Clearance Volume (Vc) :- The volume of the cylinder above top dead centre is known as clearance volume. It is denoted by V_c

Swept Volume or Stroke Volume (V_s) :- It is the volume of the cylinder covered between TDC & BDC or stroke is known as Swept volume.

Compression ratio :- It is the ratio of total volume of cylinder to the clearance volume. It is denoted by r.

$$r = \frac{V_s + V_c}{V_s}$$

where V_s = Swept volume

V_c = Clearance volume

Total Volume, $V = V_s + V_c$

$$\therefore r = \frac{V}{V_c}$$

Indicator Diagram :- It is a graph between pressure & volume. There are two types of indicator diagram
(a) Theoritical or Hypothetical
(b) Actual

Valve Timing Diagram :- The diagram showing the opening & closing of valve & injection or ignition with respect to the crank angle with TDC & BDC is known as valve Timing Diagram

Scavenging :- In a two stroke cycle engine, a blast of fresh charge is made up to enter at higher velocity in to the combustion chamber & thus drives out the burnt exhaust gases is known as scavenging.

5. OTTO (Constant Volume) Cycle.

Presented by Beau De Rochas (1862)
Applied by A. Otto (1876)

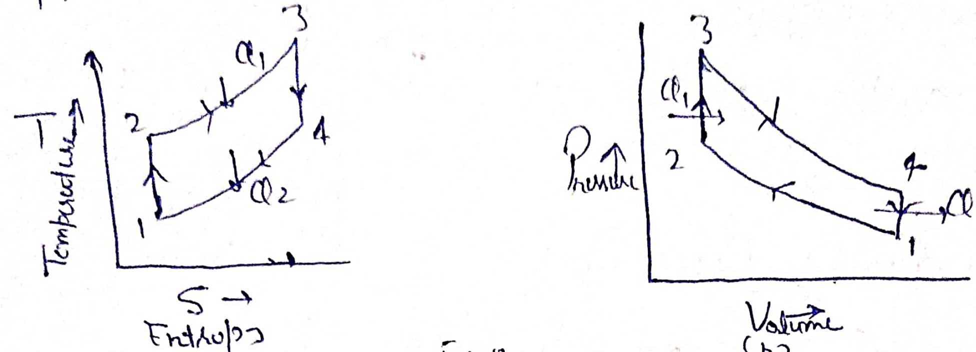


Fig 8

Process 1-2 :- Piston moves from BDC (Bottom Dead Centre) to TDC (Top dead centre) & an ideal gas with initial state 1 is compressed isentropically (reversible adiabatic) to state point 2, through compression ratio, $r = V_1/V_2$

Process 2-3 :- The piston is momentarily at rest at TDC & heat is added to the working fluid at constant volume from an external heat source which is brought in to contact with cylinder head. The pressure rises & the ratio $\alpha = P_3/P_2$ is called the explosion ratio.

Process 3-4 :- The increased high pressure exerts a greater amount of force on the piston & pushes it towards the bottom dead centre. Expansion of working fluid takes place isentropically & work is done by the systems. The volume ratio V_4/V_3 is called isentropic expansion ratio.

Process 4-1 :- The piston is momentarily at rest at BDC & heat is rejected. [illegible] & the working fluid comes to its initial state 1 & the cycle is completed.

6. Thermal η for Otto cycle:-

Consider unit mass of air undergoing the cyclic change.

Heat supplied during process 2-3

$$Q_{2-3} = C_v(T_3 - T_2)$$

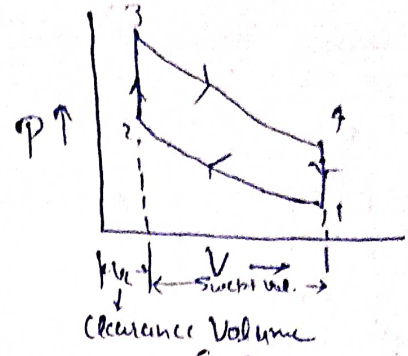


Fig 9

Heat rejected during process 4-1

$$Q_{4-1} = -C_v(T_1 - T_4) = C_v(T_4 - T_1)$$

Work done = Heat supplied - Heat rejected

$$= C_v(T_3 - T_2) - C_v(T_4 - T_1)$$

$$\text{Thermal } \eta = \frac{\text{Work done}}{\text{Heat Supplied}}$$

$$\eta = \frac{C_v(T_3 - T_2) - C_v(T_4 - T_1)}{C_v(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2} \quad \text{--- (1)}$$

In Process 1-2

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \{\because \text{adiabatic process}\}$$

$$\frac{T_2}{T_1} = r^{\gamma-1}$$

$$\Rightarrow T_1 = \frac{T_2}{r^{\gamma-1}} \quad \text{--- (2)}$$

Process 3-4

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$= \left(\frac{V_2}{V_1}\right)^{\gamma-1} \quad \{\because V_3 = V_2 \ \& \ V_4 = V_1\}$$

$$\Rightarrow T_4 = T_3 \frac{1}{r^{\gamma-1}} \quad \text{--- (3)}$$

By putting the value of (2) & (3) in (1)

$$\eta = 1 - \frac{\frac{T_3}{r^{\gamma-1}} - \frac{T_2}{r^{\gamma-1}}}{T_3 - T_2}$$

$$= 1 - \frac{1}{r^{\gamma-1}} \frac{(T_3 - T_2)}{T_3 - T_2}$$

$$\boxed{\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}}$$

Thus thermal efficiency of an otto cycle engine depends upon compression ratio r & the adiabatic exponent γ, i.e. on the nature of working medium. The thermal efficiency increases with both r & γ. In actual engines working on otto cycle, the compression ratio varies from 5 to 8 depending upon the quality of fuel.

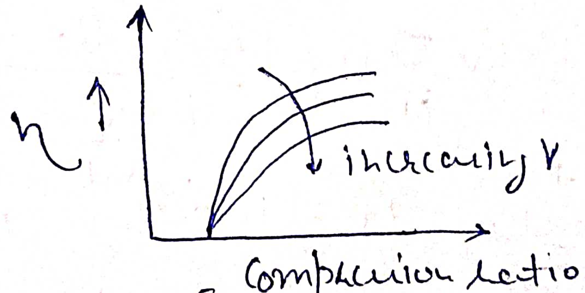


Fig 10

The curve tends to become rather flat at higher compression ratio. The which means that though the η is still increasing, the rate of increase starts diminishing.

7. <u>Mean effective pressure (mep)</u>:- The pressure variation versus volume of a reciprocating engine is plotted with the help of an engine indicator.

Mean effective pressure is defined as the average pressure acting on the piston which will produce the same output as is done by the varying pressure during a cycle.

$$mep = \frac{\text{Work done per cycle}}{\text{Swept Volume}}$$

$$= \frac{\text{Area of indicator loop}}{\text{Length of loop}}$$

Mean effective pressure for otto cycle :-

$$mep = \frac{C_v(T_3-T_2) - C_v(T_4-T_1)}{V_1-V_2}$$

$$= \frac{C_v\left[(T_3-T_2)-(T_4-T_1)\right]}{V_1\left(1-\frac{V_2}{V_1}\right)}$$

$$= \frac{C_v P_1}{R T_1}\left[\frac{(T_3-T_2)-(T_4-T_1)}{1-\frac{1}{r}}\right]$$

& $T_2 = T_1 r^{\gamma-1}$, $T_3 = T_1 \alpha r^{\gamma-1}$, $T_4 = T_1 \alpha$

$$\therefore mep = \frac{C_v}{R}\frac{P_1 r}{r-1}\left[\frac{(T_1 \alpha r^{\gamma-1} - T_1 r^{\gamma-1}) - (T_1 \alpha - T_1)}{T_1}\right]$$

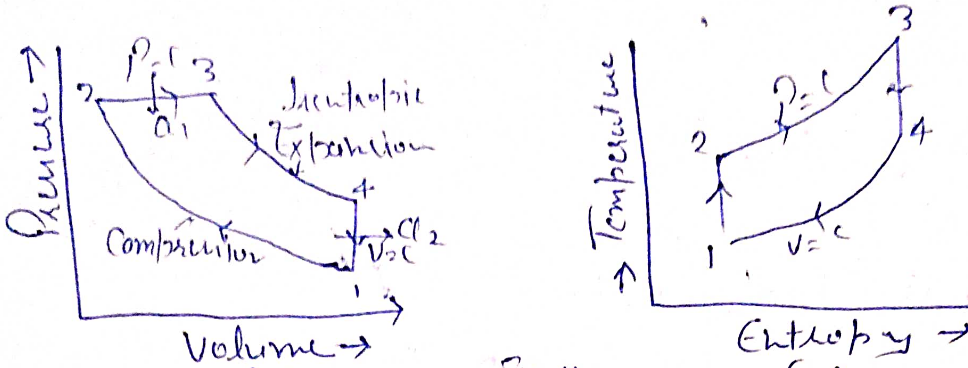
$$= \frac{C_v}{R}\frac{P_1 r}{(r-1)}\left[(r^{\gamma-1}-1)(\alpha-1)\right]$$

$$\because \frac{C_v}{R} = \frac{1}{\gamma-1}$$

$$\therefore \boxed{mep = \frac{p_1 r}{(\gamma-1)(r-1)}\left[(r^{\gamma-1}-1)(\alpha-1)\right]}$$

8. Diesel (Constant pressure) Cycle

Presented & applied by Rudolph Diesel (189



(a) Fig. 1 (b)

Process 1-2 :- Piston moves from BDC to TDC & an ideal gas with initial state 1 is compressed isentropically to state point 2, through compression ratio $r = \frac{V_1}{V_2}$

Process 2-3 :- Heat is added to compressed air at constant pressure from an external source. The heat supplied is stopped at point 3 which is called the cut-off point, & the volume ratio, $\rho = V_3/V_2$ is called cut-off ratio or isobaric expansion ratio.

Process 3-4 :- The increased high pressure exerts a greater amount of force on the piston & pushes it towards BDC. Isentropic expansion takes place.

Process 4-1 :- The piston is momentarily at rest at BDC & heat is rejected to external sink by bringing it in contact with the cylinder head. The process is so controlled that ultimately the air comes to its initial state 1 & the cycle is completed.

The low speed diesel engine works on a cycle which is slight modification of the Diesel cycle.

9. Thermal efficiency for Diesel cycle

Consider unit mass of air undergoing the cyclic change.

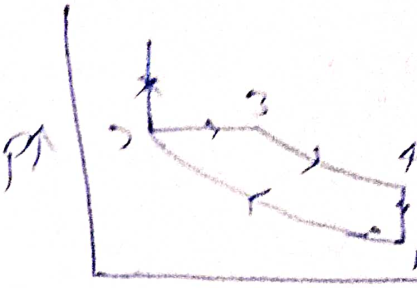


Fig 13

Heat supplied during process 2-3

$Q_{2-3} = C_p(T_3 - T_2)$

Heat rejected during process 4-1

$Q_{4-1} = -C_v(T_1 - T_4) = C_v(T_4 - T_1)$

Work Done = Heat supplied - Heat rejected

$$\text{Thermal efficiency} = \frac{\text{Work Done}}{\text{Heat supplied}}$$

$$= \frac{C_p(T_3 - T_2) - C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$\eta_{diesel} = 1 - \frac{1}{\gamma}\frac{(T_4 - T_1)}{T_3 - T_2} \quad (1)$$

Process 1-2 :- $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \Rightarrow T_2 = T_1 r^{\gamma-1}$ (2) $\{\because \frac{V_1}{V_2} = r\}$

Process 2-3 :- $\frac{T_3}{T_2} = \frac{V_3}{V_2} \Rightarrow T_3 = T_2 \rho$ $\{\because \frac{V_3}{V_2} = \rho\}$

$\Rightarrow T_3 = T_1 r^{\gamma-1} \rho$ — (3) $\{\because$ From (2)$\}$

Process 3-4 :- $\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma-1}$

$T_4 = T_3 \left(\rho \times \frac{1}{r}\right)^{\gamma-1}$ $\{\because V_4 = V_1$ & $\frac{V_2}{V_1} = \frac{1}{r}\}$

$T_4 = T_1 r^{\gamma-1} \rho \left(\rho^{\gamma-1} \times \frac{1}{r^{\gamma-1}}\right)$

$= T_1 \rho^{\gamma}$ — (4)

From (2), (3), (4) values, put in (1)

$$\eta = 1 - \frac{1}{\gamma}\frac{T_1 \rho^{\gamma} - T_1}{T_1 r^{\gamma-1}\rho - T_1 r^{\gamma-1}}$$

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

∴ The efficiency of Diesel cycle depends upon the compression ratio (r), & cut off ratio (ρ) & hence upon the quantity of heat supplied.

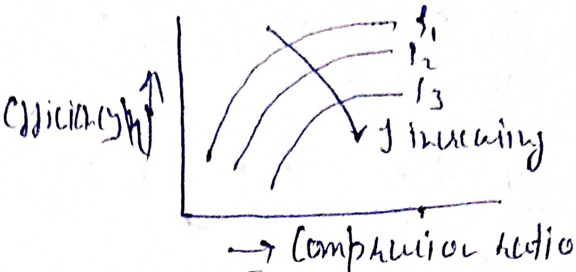


Fig. 13

Further examination of factor $K = \left[\dfrac{(\rho^{\gamma}-1)}{\gamma(\rho-1)}\right]$ reveals that with an increase in the cut-off ratio ρ, the value of K increases. That implies that for a diesel engine at constant pressure ratio, the efficiency would increase with decrease in ρ & in the limit $\rho \to 1$, the efficiency would become $\eta = 1 - \dfrac{1}{r^{\gamma-1}}$

Since the factor $K = \left[\dfrac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$ is always greater than unity, the Diesel cycle is always less efficient than a corresponding otto cycle having same compression ratio.

10. <u>Mean effective pressure</u>:-

$$\text{Work done} = C_p(T_3 - T_2) - C_v(T_4 - T_1)$$

$$\text{Swept volume} = V_1 - V_2$$

$$= V_1\left(1 - \frac{V_2}{V_1}\right)$$

$$= \frac{RT_1}{P_1}\left(1 - \frac{1}{r}\right) = \frac{RT_1}{P_1 r}(r-1)$$

$$mep = \frac{W.D}{\text{Swept volume}} = \frac{C_p(T_3-T_2) - C_v(T_4-T_1)}{RT_1/P_1 r\,(r-1)}$$

$$= \frac{C_p}{R}\frac{P_1 r}{r-1}\left[\frac{r(T_3-T_2) - (T_4-T_1)}{T_1}\right] \quad (1)$$

As $T_2 = T_1 r^{\gamma-1}$, $T_3 = T_1 \rho r^{\gamma-1}$ (In previous find out).

& $T_4 = T_1 \rho^{\gamma}$

$$\therefore mep = \frac{C_v}{R}\frac{P_1 r}{r-1}\left[\frac{\gamma(T_1 \rho r^{\gamma-1} - T_1 r^{\gamma-1}) - (T_1 \rho^{\gamma} - T_1)}{T_1}\right]$$

$$= \frac{C_v}{R}\frac{P_1 r}{r-1}\left[\gamma r^{\gamma-1}(\rho-1) - (\rho^{\gamma}-1)\right]$$

$$\because \frac{C_v}{R} = \frac{1}{\gamma-1}$$

$$\therefore \boxed{mep = \frac{P_1 r}{(\gamma-1)(r-1)}\left[\gamma r^{\gamma-1}(\rho-1) - (\rho^{\gamma}-1)\right]}$$

11. Dual Combustion (Mixed or Composite) Cycle or Limited Pressure Cycle

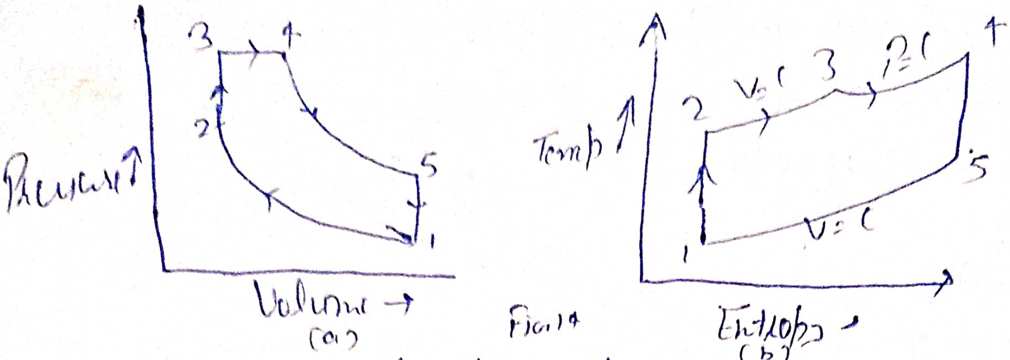


Fig 1.4

This is a cycle in which the addition of heat is partly at constant volume & partly at constant pressure.

Process 1-2 :- Piston moves from BDC to TDC & air with initial state 1 is compressed isentropically to state point 2 through compression ratio. $r = \frac{V_1}{V_2}$

Process 2-3 :- The piston is momentarily at rest at TDC & heat is added to air at constant volume from external heat source which is brought into contact with the cylinder head. The pressure rises & the ratio $\alpha = P_3/P_2$ is called the explosion ratio.

Process 3-4 :- Addition of heat at constant pressure during which preliminary expansion of air takes place. The heat supply is stopped at point 4 which is called the cut-off point. That ratio V_4/V_3 is called the cut-off ratio or isobaric expansion ratio.

Process 4-5 :- Expansion of air takes place isentropically & the work is done by the system. The volume ratio V_5/V_4 is called the isentropic expansion ratio.

Process 5-1 :- The piston is momentarily at rest at ODC & heat is rejected to the external sink by bringing it in contact with the cylinder head.

The process is so controlled that ultimately the initial parameters are restored & the cycle is completed.

The high speed diesel engine works on a cycle which is slight modification of Dual cycle.

12. Thermal η for Dual Cycle :-

Consider unit mass of air undergoing the cyclic change

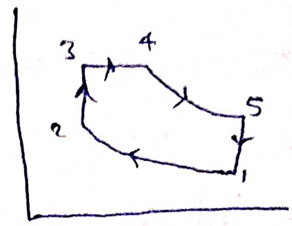


Fig 15

Heat added Q_1,

= Heat added during process 2-3
+ Heat added during process 3-4

$= C_v(T_3 - T_2) + C_p(T_4 - T_3)$

Heat rejected, Q_2 = Heat rejected during constant volume process 5-1

$= C_v(T_5 - T_1)$

Work Done = Heat supplied − Heat rejected

$= C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)$

Thermal efficiency, $\eta = \dfrac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$= 1 - \frac{T_5 - T_1}{(T_3 - T_2) + \gamma(T_4 - T_3)} \quad \text{(A)}$$

Here Compression ratio $r = \dfrac{V_1}{V_2}$

Explosion ratio $\alpha = P_3/P_2$

Cut-off ratio $\rho = \dfrac{V_4}{V_3}$

Expansion ratio $r_e = \dfrac{V_5}{V_4} = \dfrac{r}{\rho}$ $\left\{ r_e = \dfrac{V_5}{V_4} \times \dfrac{V_2}{V_2} = \dfrac{V_1}{V_2} \times \dfrac{V_3}{V_4} = \dfrac{r}{\rho} \right\}$

(1)

Process 1-2 :- Adiabatic process (Compression)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = T_1 r^{\gamma-1} \quad \text{--- (1)}$$

Process 2-3 Isochoric Process

$$\frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$\Rightarrow T_3 = T_2 \alpha$$

$$= T_1 r^{\gamma-1} \alpha \quad \text{--- (2)} \quad \{\because \text{From (1)}\}$$

Process 3-4 :- Isobaric process

$$\frac{T_4}{T_3} = \frac{V_4}{V_3}$$

$$T_4 = T_1 r^{\gamma-1} \alpha \rho \quad \text{--- (3)} \quad \{\because \text{From (2)}\}$$

Process 4-5 Adiabatic (Reversible) expansion process

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1}$$

$$T_5 = T_4 \left(\frac{1}{r_e}\right)^{\gamma-1} = T_4 \left(\frac{\rho}{r}\right)^{\gamma-1}$$

$$= T_1 r^{\gamma-1} \alpha \rho \frac{\rho^{\gamma-1}}{r^{\gamma-1}} \quad \{\because \text{From (3)}\}$$

$$= T_1 \alpha \rho^{\gamma} \quad \text{--- (4)}$$

By putting the value of (1), (2), (3) & (4) in (A)

$$\eta = 1 - \frac{T_1 \alpha \rho^{\gamma} - T_1}{(T_1 r^{\gamma-1} \alpha - T_1 r^{\gamma-1}) + \gamma(T_1 r^{\gamma-1} \alpha \rho - T_1 r^{\gamma-1} \alpha)}$$

$$\boxed{\eta_{dual} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{\alpha \rho^{\gamma} - 1}{(\alpha - 1) + \gamma \alpha (\rho - 1)}\right]}$$

It is apparent from the above expression that the thermal efficiency of a mixed cycle can be increased by supplying a greater portion of heat at constant volume (high value of α) & smaller portion at constant pressure (low value of ρ). In the actual high speed diesel engines operating on this cycle, it is achieved by early fuel injection & an early cut-off.

13. Mean effective pressure (mep):-

$$mep = \frac{\text{Work done per cycle}}{\text{Swept Volume}}$$

Work done = Heat supplied − heat rejected

$$= C_v(T_3-T_2) + C_p(T_4-T_3) - C_v(T_5-T_1)$$

Swept Volume $= V_1 - V_2$

$$= V_1\left(1-\frac{V_2}{V_1}\right)$$

$$= \frac{RT_1}{P_1}\left(1-\frac{1}{r}\right) = \frac{RT_1}{P_1 r}(r-1)$$

$$mep = \frac{C_v}{R}\frac{P_1 r}{(r-1)}\left[\frac{(T_3-T_2)+\gamma(T_4-T_3)-(T_5-T_1)}{T_1}\right]$$

As previous $T_2 = T_1 r^{\gamma-1}$, $T_3 = T_1\alpha r^{\gamma-1}$

$T_4 = T_1\alpha\rho r^{\gamma-1}$, $T_5 = T_1\alpha\rho^{\gamma}$

$$\therefore mep = \frac{C_v}{R}\frac{P_1 r}{r-1}\left[\frac{(T_1\alpha r^{\gamma-1} - T_1 r^{\gamma-1}) + \gamma(T_1\alpha\rho r^{\gamma-1} - T_1\alpha r^{\gamma-1}) - (T_1\alpha\rho^{\gamma} - T_1)}{T_1}\right]$$

$$= \frac{C_v}{R}\frac{P_1 r}{r-1}\left[(\alpha-1)r^{\gamma-1} + \gamma\alpha r^{\gamma-1}(\rho-1) - (\alpha\rho^{\gamma}-1)\right]$$

But $\frac{C_v}{R} = \frac{1}{\gamma-1}$

$$\therefore mep = \frac{P_1 r}{(r-1)(\gamma-1)}\left[(\alpha-1)r^{\gamma-1} + \gamma\alpha r^{\gamma-1}(\rho-1) - (\alpha\rho^{\gamma}-1)\right]$$

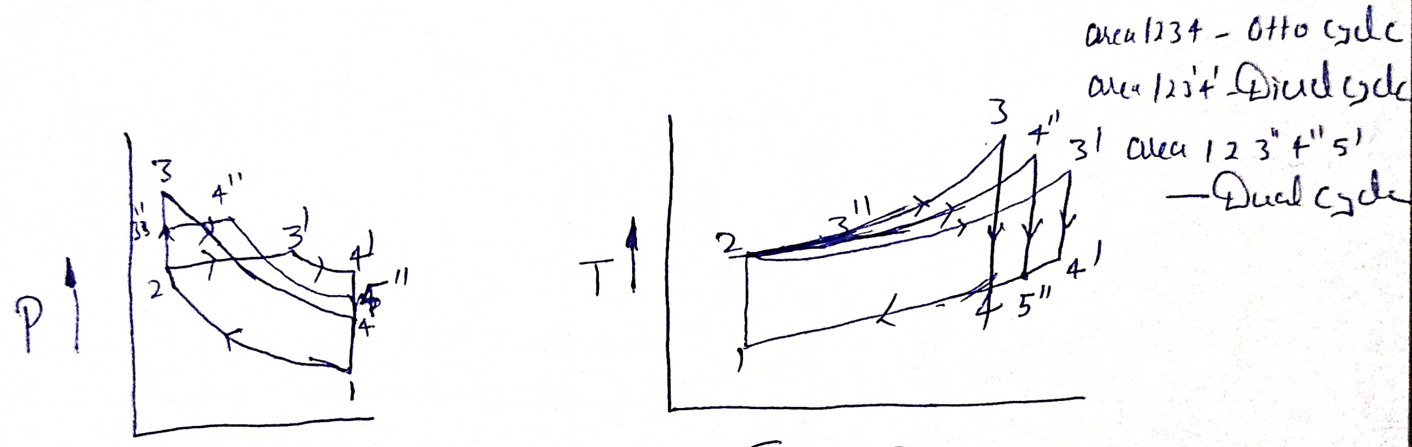
5.

14. Comparison of Otto, Diesel & Dual Cycles

(with the help of P-V & T-S Diagrams)

(a) For the same compression ratio & same heat input:

When compression ratio is kept constant, process 1-2 remain same for all the three cycles as shown in fig (a) & (b). For same heat input, the magnitude of processes 2-3, 2-3', 2-3''-4'' should be same



(a) Fig 16 (b)

for all the three cycles. The work done during the cycle is proportional to the area inside the bounded region. If heat input is same, hence η (efficiency) is proportional to the area inside the bounded region.

Hence it is clear from the fig (a) & b

Area covered by region 1234 > Area covered by region 123''4''5' > Area covered by region 123'4',

∴ $\eta_{otto} > \eta_{dual} > \eta_{diesel}$

(b) for same maximum pressure & same heat input

When the maximum pressure is same, the points 3, 3', & 3'' must be on same line & for the same heat input, the magnitude of process 2-3, 2-3', 2-3''-4'' should be same as shown in fig (a) & (b)

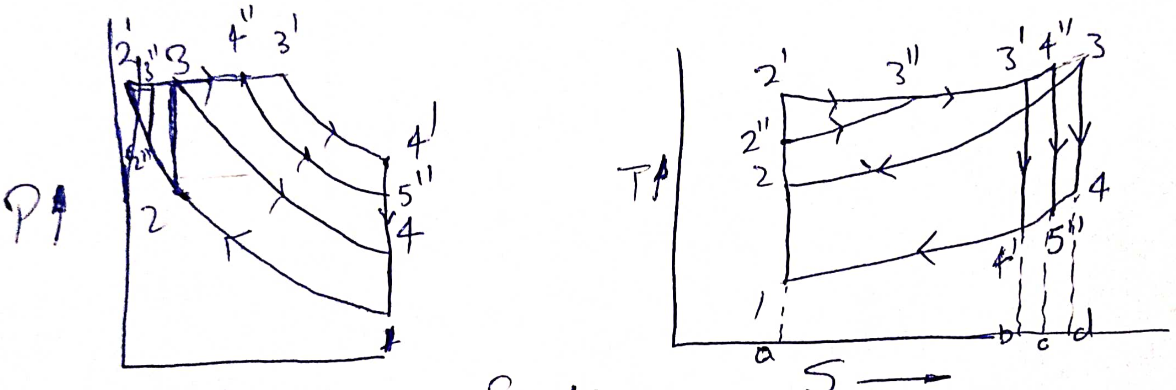


Fig 17

(a) Area 1-2-3-4-1 – Otto cycle

(b) Area 1-2-3'-4'-1 Diesel cycle

Area 1-2''-3''-4''-5''-1 Dual cycle

It is clear from the T-S diagram that the heat rejected by the diesel cycle (area 1-4'-b-a) is less than the heat rejected by otto cycle (area 1-4-d-a)

Since $\eta = 1 - \frac{\text{heat rejected}}{\text{heat input}}$

Hence, the Diesel cycle is more efficient than the Otto cycle for same maximum pressure & heat input. The dual cycle efficiency falls between the otto & diesel cycle.

$$\eta_{diesel} > \eta_{dual} > \eta_{otto}$$

(c) For same maximum pressure & temperature :-

This is the case, you can say that there is same heat rejection take place. Clearly from fig For same maximum pressure & temperature, point 3 is common in all the three cycles & for same heat rejection process 4-1 is common in all the three cycles.

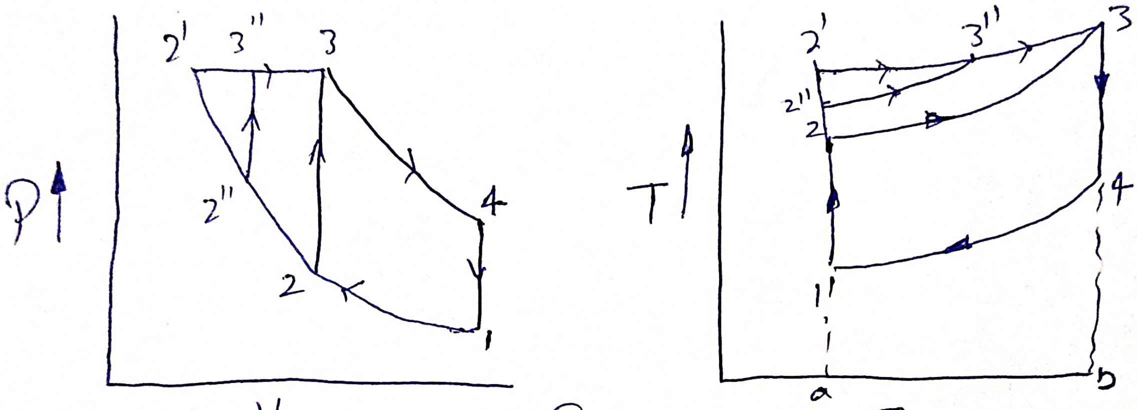


Fig 19

(a) (b)

area - 1-2-3-4-1 → Otto cycle

area - 1-2'-3-4-1 → Diesel cycle

area - 1-2''-3''-3-4-1 - Dual cycle.

It is clearly from fig the heat supplied to the diesel cycle on T-S diagram (area-a-2'-3-4-b-a) is more than that of the otto cycle (area-a-2-3-4-b-a). Dual cycle again falls between the otto cycle & diesel cycle.

Since, $\eta = 1 - \frac{\text{Heat rejected}}{\text{Heat supplied}}$

$$\therefore \eta_{diesel} > \eta_{dual} > \eta_{otto}$$

15. FOUR STROKE PETROL ENGINE.

All events of the cycle namely suction, compression, combustion, & expansion, & exhaust are completed in two revolutions of the crankshaft.

The salient features of the four strokes in a petrol engine are as given below.

1. Intake or suction stroke :-

Initially the piston is at top dead centre (TDC) position, the inlet valve is open & the outlet valve is closed. The piston moves downwards towards bottom dead centre (BDC) position & the pressure inside the cylinder is reduced to a value below the atmosphric pressure. The vacuum thus created causes the charge to rush in & fill the space vacated by the piston. The charge consists of a mixture of air & petrol prepared by the carburettor. The suction continues till the piston reaches the it's BDC position. The piston has now made one stroke & the crankshaft has turned through 180°c i.e has made half the revolution.

2. Compression Stroke :-

Both the valves (Inlet & Outlet) are closed & the movement of the piston is from BDC to TDC position. The charge inside the cylinder is compressed to clearance volume; the volume decreases & there is a continuous rise both in temperature & pressure of the charge. The compression ratio is 5:1 to 8:1.

3. Power stroke :-

When the piston reaches at TDC position, the charge is ignited by causing an electric spark between the electrodes of a spark plug

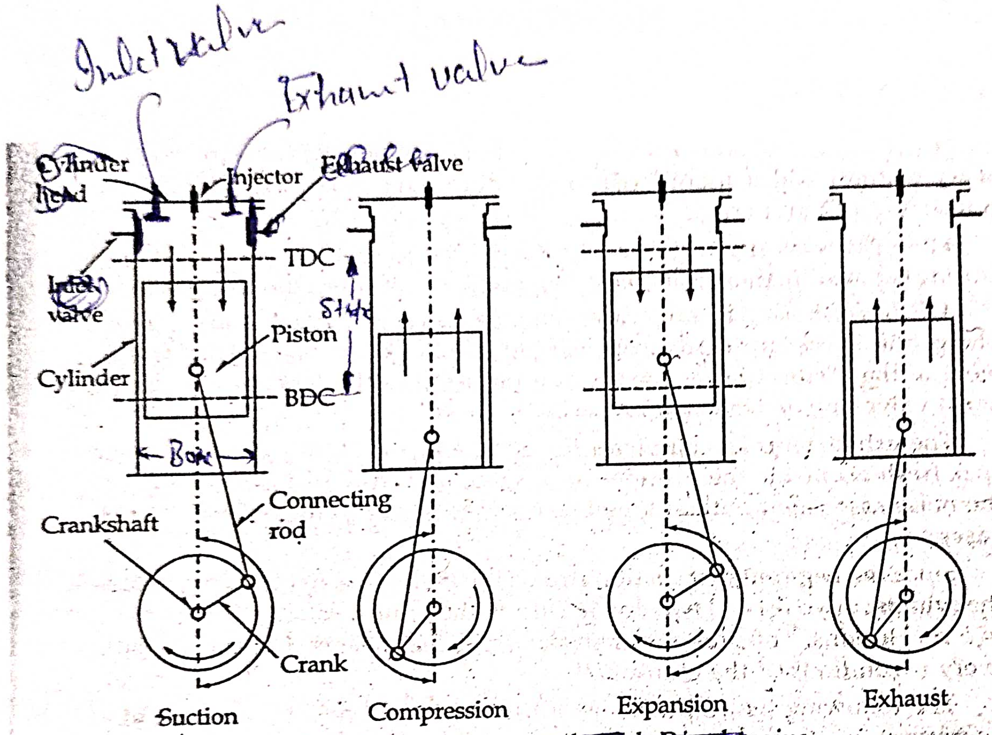


Fig. 5.7. ~~Operation of a four stroke cycle Diesel~~ *engine*

(a) (b) (c) d

Fig 20

Process of four stroke petrol engine

Fig 21

which is located in the cylinder head. During combustion, the chemical energy of the fuel is released & there is rise both in pressure & temperature of the gases at almost constant volume. The temperature of gases increases to about 1800-2000°C. & the pressure reaches 30-40 bar.

With both valves closed, the gases at increased pressure & temperature expand, push the piston down the cylinder & work is done by the system. During expansion, there is increase in volume of the gases & the pressure drops to as low as 3 bar.

4. Exhaust stroke :-

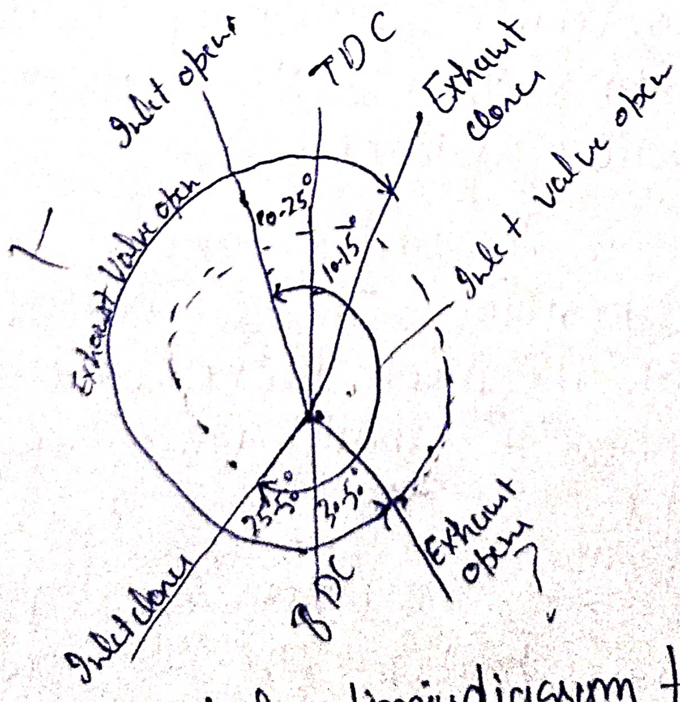
The inlet valve remain closed but the exhaust valve opens when the piston reaches BDC position towards the completion of power stroke. The pressure falls slightly above atmospheric pressure at constant volume. The piston moves upwards from BDC to TDC & this upward movement of the piston pushes the spent up gases in to the atmosphere through exhaust valve.

16. FOUR STROKE DIESEL ENGINE :-

This engine works on Diesel cycle or constant pressure cycle. Heavy motor vehicles, stationary power plants, big industrial units & ships mostly employ this engine. Its various strokes are as follows:

1. Suction stroke :- The piston moves down from the top centre position. The air is drawn in to the cylinder through the inlet valve which closes at the end of this stroke. The exhaust valve remain closed during this stroke.

2. Compression stroke :- The piston moves up from the bottom dead centre position. The inlet valve is also now closed. The air is drawn in to cylinder



Valve timing diagram for four stroke engine in the previous stroke is entrapped inside the cylinder & compressed with upward movement of the piston. As the compression ratio used in the engine is high (14 to 22), the air is finally compressed to a pressure as high as 40 bar at which its temperature is high (as high as 1000°c) enough to ignite the fuel.

3. Power stroke :- As the piston moves after reaching top dead centre the fuel is injected in to hot compressed air where it start burning, maintaining the pressure constant. At a point, the fuel supply is cut-off. Theoretically, the fuel is injected at the end of compression stroke & injection continues till the point of cut-off. Both inlet & outlet valves remain closed during this stroke. The hot gases & air now expands adiabatically, in the engine cylinder pushing the piston down & hence doing work. The piston finally reaches the bottom dead centre.

4. Exhaust stroke :- The piston now moves up again. The inlet & ~~outlet~~ fuel valves are closed but the exhaust valve opens. A greater part of burnt gases escape due to their own expansion. The upward movement of the piston pushes the remaining gases out through the open exhaust valve.

17 Valve Timing Diagram of four stroke engines

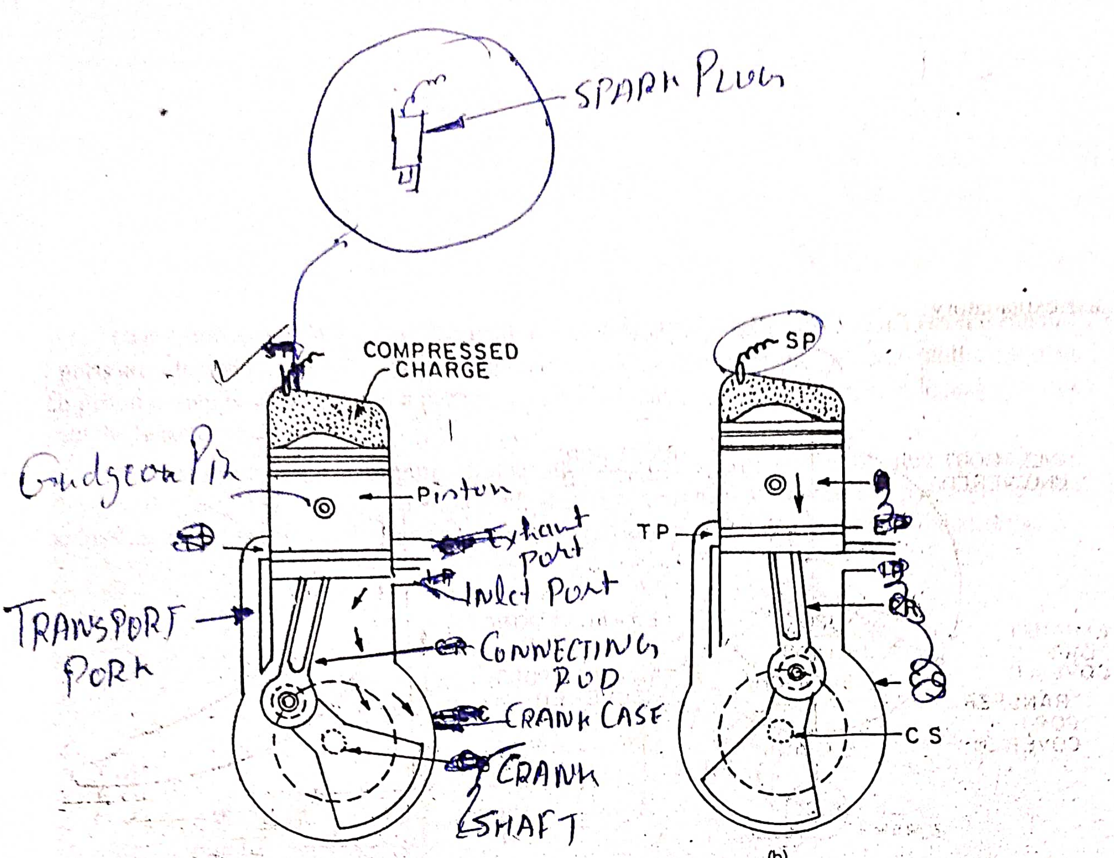
Inlet valve opens 10°-25° in advance of TDC

Closes 25°-50° after the BDC

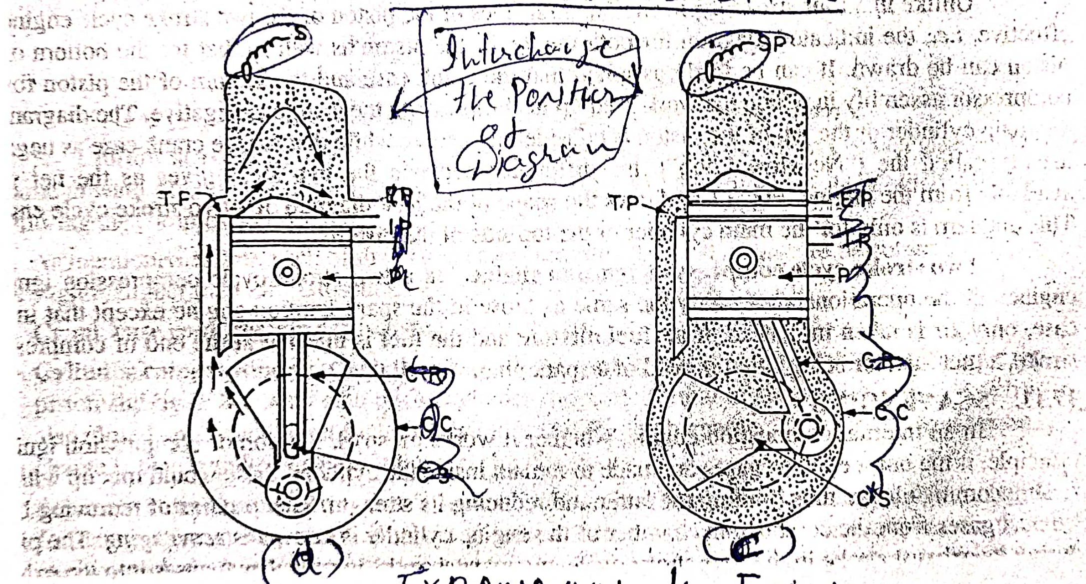
Exhaust valve opens 30°-50° in advance of the BDC

Closes 10°-15° after TDC.

Fuel injection starts 5°-10° before TDC in compression stroke depending upon the speed of engine & continues up to 15°-25° after TDC in working TDC in working stroke.



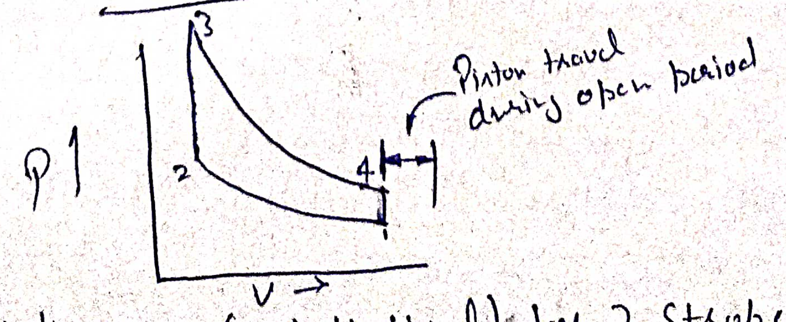
COMPESSION & SUCTION



EXPANSION & EXHAUST

Fig 2 3 (i)

WORKING OF 2-Stroke cycle Engine (SI)



P-V diagram (Hypothetical) for 2-Stroke SI engine

Fig 2 3 (ii)

18. Two Stroke Cycle Engine :- (Petrol or SI) ①

There is one working stroke in one cycle of four stroke cycle engines i.e. in two revolutions of crankshaft. The desire to have one working stroke per cylinder for every revolution of the crankshaft had led to the development of two stroke cycle engines.

In a two stroke cycle engine, the suction & exhaust strokes are eliminated. Here the burnt exhaust gases are forced out through the exhaust port by a fresh charge of the fuel which enters the cylinder nearly at the end of the working stroke through the inlet port. The process is termed as scavenging.

Fig 1 shows a two stroke petrol engine commonly used in motor cycles. It has no valves but consists of the inlet or induction port (IP), exhaust port (EP) & a third port called the transfer port (TP).

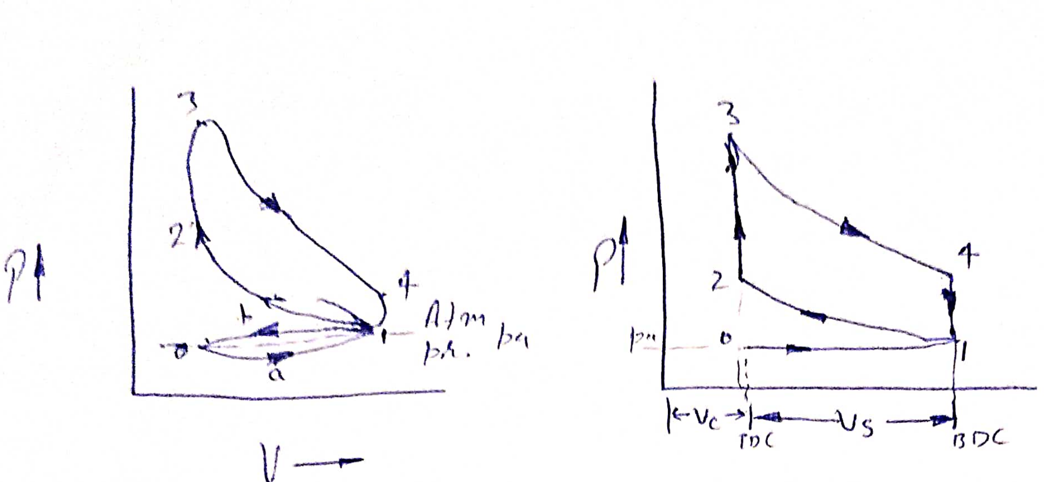
Referring to fig 1(a) let the piston be nearing the completion of its compression stroke. The ignition starts due to the spark given by the spark plug & the piston is pushed down 1(b) & 1(c) performing the working stroke & in doing so, the air-fuel mixture already drawn from the inlet port in the previous stroke is compressed to a pressure of about of 1.4 bar. When about 4/5th of this stroke is completed, the exhaust port (EP) is uncovered slightly & some of the charge of burnt gases escape to the atmosphere. Immediately afterwards as the exhaust port is ~~p~~ uncovered by further downward movement of the piston, the transfer port (TP) which is only very slightly lower than (EP) is also uncovered and (1d)

& a charge of compressed fuel-air-mixture enters the cylinder & further pushes out the burnt gases out of the exhaust port (EP). The top of the piston is made of a particular shape that facilitates the deflection of fresh charge upwards & thus avoids its escape along with the exhaust gases. After reaching the bottom dead centre, when the piston moves up it first closes the transfer port (TP) & then the exhaust port (EP). The charge of fuel which previously entered the cylinder is now compressed. Simultaneously there is a fall of pressure in the crank case creating a partial vacuum. When the piston is nearing its upward movement, the inlet port opens & a fresh charge of air-fuel mixture from the carburettor enters the crank case. After the ignition of the charge takes place, the piston moves down for the power stroke & the cycle is repeated as before.

15. Two stroke cycle compression ignition engine. In two stroke cycle compression ignition engine, all the operations are exactly the same as those in the spark ignition engine except that in this case, only air is taken instead of air fuel mixture & the fuel is injected at the end of compression stroke, a fuel injector being fitted instead of a spark plug.

20: Actual P-V Diagram for four-stroke engine

(a) Otto Cycle engine



Actual - P-V Diagram (a)   (b) Hypothetical or Theoritical P-V Diagram

Fig 24

Actual indicator (P-V) diagram differs from hypothetical one due to following reasons

1. The corners are rounded off, because the inlet & outlet valves do not open & close suddenly but take some time to do so.

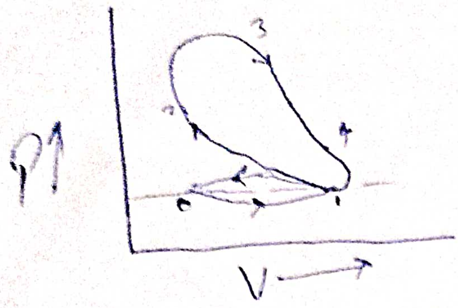
2. Due to the resistance of inlet valve to the entering charge, the actual pressure inside the cylinder during suction is slightly less than the atmospheric pressure.

3. Due to resistance of outlet valve to the exhaust gases leaving the cylinder during exhaust stroke is slightly higher than the atmospheric pressure.

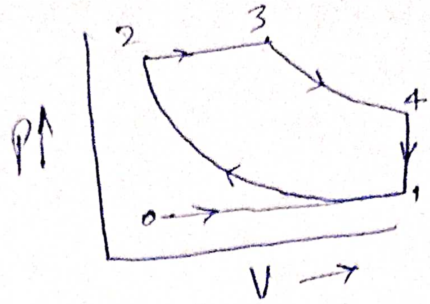
4. Due to friction, compression & expansion are not isentropic.

5. Combustion of fuel charge does not take place at constant volume & the pressure rise is not along a straight line due to time lag between the ignition of charge & its combustion i.e. there is progressive combustion.

(b.) Diesel cycle engine



(a) Actual P.V diagram



(b) Hypothetical P.V Diagram

Fig. 25

The reasons are nearly same as explained in ottocycle engine for deviation of actual cycle from theoritical cycle. The same reasons, we can described in this way also.

1. Time loss factor i.e. time taken to open & close the inlet & outlet valve as well as time taken for combustion.
2. Gas leakage & fluid friction take place in actual ~~engine~~ cycle.
3. Loss of heat take place from gases to cylinder walls.
4. Loss of work take place on the exhaust stroke due to early opening of the exhaust valve.

21. Comparison between Two-stroke cycle & four stroke cycle engines

Two-stroke Cycle	Four-Stroke cycle
1. The working cycle is completed in two-strokes of the piston or in one revolution of the crank shaft. So, one power stroke is obtained in each revolution of crankshaft.	1. The working cycle is completed in four strokes of the piston or in two revolution of the crankshaft. Thus, one power stroke is obtained in every two revolution of the crankshaft.
2. A lighter flywheel is needed because power is obtained in each revolution of crank shaft i.e. turning movement is uniform.	2. A heavier flywheel is needed because power is obtained in every two revolution of the crankshaft i.e. turning movement is not so uniform.
3. The engine is light & compact for same power output.	3. The engine is heavy & bulky for same power output.
4. Simple in design, due to absence of cams, camshaft valve etc., only ports are present.	4. Complicated in design, due to valve & valve mechanism.
5. The initial cost of a two stroke engine is less due to light weight & absence of valve & valve mechanism.	5. The initial cost of four stroke engine is high due to bulky & presence of valve & valve mechanism.
6. Greater rate of wear & tear due to firing in each revolution of crankshaft. Hence, more cooling & lubrications required.	6. Lesser rate of wear & tear Hence, lesser cooling & lubrication required.

Two-Stroke Cycle	Four-Stroke Cycle
7. Thermal efficiency of a two-stroke engine is lower due to some charge escaping without burning & poor scavenging.	7. Thermal efficiency of a four-stroke engine is higher because of proper combustion of fuel take place inside the cylinder.
8. Volumetric efficiency is more due to greater time of induction.	8. Volumetric efficiency is less due to lesser time of induction
9. Noisy exhaust due to sudden release of burnt gases. Hence causes more pollution.	9. It causes less pollution due to proper combustion of fuel inside the chamber.
10. Mechanical efficiency is more due to one power stroke in each revolution of crankshaft.	10. Mechanical efficiency is less due to one power stroke in every two revolution of crankshaft.
11. It is used where uniform turning movement is required. For example - in ship propulsion.	11. It is used where fuel economy is prime concern For example:- cars, buses, trucks, tractors, industrial engines

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22. COMPARISON BETWEEN SI & CI Engine

S. No.	Basis	SPARK IGNITION Engines	COMPRESSION IGNITION Engines
1.	Basic Cycle	The petrol or SI engine works on otto cycle.	The diesel or CI engine works on diesel cycle.
2.	Compression ratio range	The compression ratio is kept between 5:1 to ~~10.5~~ 10.5 :1. The upper limit is fixed by anti-knock rating of fuels.	The compression ratio is kept between 14:1 to 22:1. The upper limit is limited by the rapidly increasing weight of the engine.
3.	Fuel used	SI engine is a light oil engine & uses petrol as fuel.	Diesel is used as fuel.
4.	Induction of fuel	Mixture of fuel & air introduced as gaseous mixture in the suction stroke through carburettor	Fuel is injected directly in to combustion chamber at high pressure at the end of compression stroke through fuel ~~injector~~ injector.
5.	Ignition	Spark plug is required for ignition of fuel	Self ignition take place due to high temperature & pressure of ~~the~~ air, when fuel is injected.
6.	Thermal efficiency	Lower thermal efficiency due to low compression ratio.	Higher thermal efficiency due to high compression ratio.
7.	Weight	Lighter in weight for giving same power output	Heavier in weight for giving same power output.
8.	Cost	Low maintenance cost but high running cost.	Higher maintenance cost but low running cost.

S.No.	Basis	SI Engine	CI Engine
9.	Speed	Higher rpm (revolution per minute) due to lighter weight.	low speed due to heavy weight
10.	Load control or Governing	The SI engines are quantity governing by throttling. In accordance with load & speed of engine, the air-fuel mixture inducted through throttle valve	The CI engines are quality governing engines The composition of the mixture (air-fuel ratio) is changed by the mixture being inducted by admitting more or less fuel injected into chamber space.
11.	Operating pressures	Compression pressure is between 7 to 15 bar where as maximum pressure is in between 45 to 50 bar	Compression pressure is in between 30-50 bar. Whereas maximum pressure is in between 60-70 bar
12.	Fire hazard	Volatile fuel is used, hence more fire hazard	Less volatile fuel is used, hence less fire hazard
13.	Initial cost	The initial cost is low	The initial cost is high due to heavy weight & due to cost of fuel pum[p]
14	Specific fuel Consumption	At full load sfc (specific fuel consumption) is medium, where as it is worse at part load & idling	At full load sfc is better whereas at part load it is much better than SI, as there is no throttling.

23.

Gas Turbine - An Introduction

The modern gas turbine is not far different so long as the working principle is concerned, from a wind mill but in order to have an efficient operation, the moving air or gas is properly controlled & directed against the blades of the turbine wheel. The flow of working fluid in the turbine may be radial or axial, the latter being more commonly used. A jet of hot gases & air-mixture is made to flow over rings of moving blades mounted on the shaft & in doing so velocity of jet decreases & its kinetic energy is absorbed by the rings of blades imparting rotary motion to the shaft. A larger part of power developed by turbine rotor is consumed for driving a compressor which supplies air under pressure to a combustion chamber while remaining power is utilised for doing the external work.

The basic principle on which a gas turbine work is that air is made to enter the prime mover compressed, heated by the combustion process & thus raising the pressure still further expanded & finally the expanded products are rejected through the exhaust. The fuel used for combustion in a gas turbine plant may be oil, coal gas, producer gas, blast furnace gas & even pulverised coal or peat.

Classification of Gas Turbines

- Constant pressure or Continuous Combustion type
  - Open cycle
  - Closed cycle
- Constant volume or Explosion type

24. MERITS OF GAS TURBINES

(i) Merits over I.C. engine

1. The mechanical efficiency of a gas turbine (95%) is quite high as compared with I.C engine (85%).

2. A gas turbine does not require a flywheel as the torque on the shaft is continuous & uniform. Whereas a flywheel is a must in case of I.C engines.

3. The weight of gas turbine per H.P. developed is less than that of I.C. engine.

4. The gas turbine can be driven at very high speeds (40,000 rpm) whereas this is not possible with I.C. engines.

5. The work developed by gas turbine per kg of air is more as compared to I.C engines. This is due to fact that the gases can be expanded up to atmospheric pressure in case of a gas turbine whereas in an I.C. engine expansion up to atmospheric pressure is not possible.

6. The components of gas turbine can be made lighter since the pressures are very low, say 5 bar compared with I.C engines, say 60 bar.

7. In gas turbine the ignition & lubrication systems are much simpler as compared with I.C. engines.

8. Cheaper fuels such as paraffine type, residual oils or powdered coal can be used whereas special fuels are employed in petrol engine to check knocking

25. Demerits of gas turbines :-

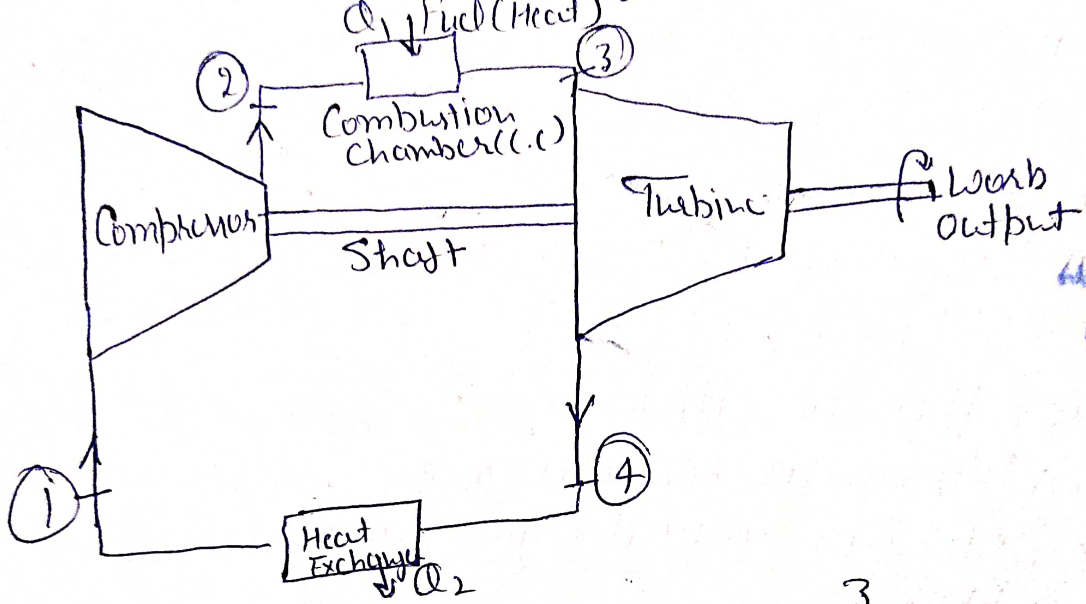
1. The thermal efficiency of gas turbine is low (15-20%) as compared with I.C. engines (25-30%)
2. With wide operating speeds the fuel control is comparatively difficult.
3. Due to higher operating speeds of the turbine, it is imperative to have a speed reduction device.
4. It is difficult to start a gas turbine as compared to an I.C. engine
5. The gas turbine blades needs a special cooling system.
6. One of main disadvantage of a gas turbine is its very poor thermal efficiency at part loads, as the quantity of air remains same irrespective of load & output is reduced by reducing the quantity of fuel supplied.
7. Owing to the use of nickle-chromium alloy, the manufacture of the blades is difficult & costly
8. For the same output the gas turbine produces five times exhaust gases than I.C. engine.

(ii) Merits of over steam turbines

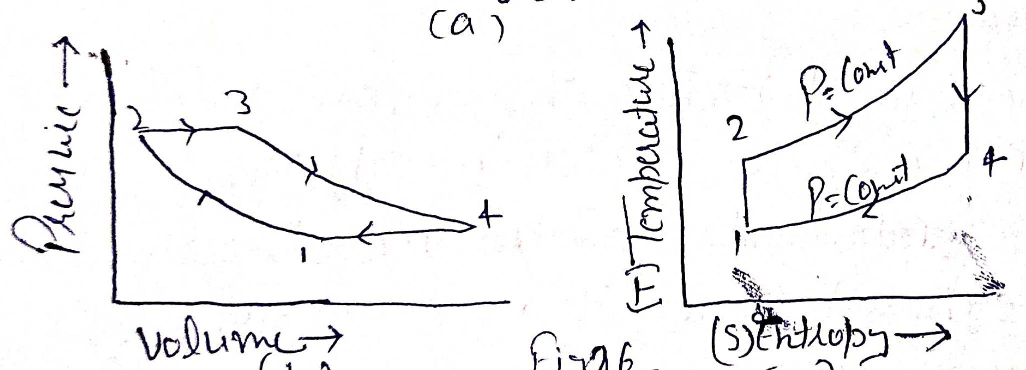
1. Capital & running cost less.
2. For the same output the space required is far less.
3. Starting is more easy & quick.
4. Weight per H.P. is far less.
5. Can be installed anywhere.
6. Control of gas turbine is much easier.
7. Boiler along with accessories not required.

26. Constant pressure gas turbine cycle or Brayton Cycle or Joule cycle

It is a theoritical cycle on which run the constant pressure gas turbines. Gas turbine is a rotary machine & operates under steady & continuous supply of working medium.



(a)



(b) Fig 26 (c)

The schematic arrangement of different components of a gas turbine plant &, P-V & T-S plots for an ideal Brayton Cycle are shown in fig.1. The cycle consists of two isentropic process (compression & expansion) & two constant pressure process (combustion & exhaust). The sequence of operations is

1-2:- Isentropic compression air in a rotary compressor which raises the pressure & temperature of air P_1, T_1 to $P_2 T_2$, 2-3: The air at condition 2 is passed through a heat exchanger where heat is externally supplied to it at constant pressure. This raises the temperature from T_2 to T_3.

3-4: Isentropic expansion of high temperature & high pressure air in the turbine during which work is done by the system.

4-1: The air at state point 4 is passed through a heat exchanger & heat is rejected at constant pressure. This cools the air to initial condition 1 & the cycle is completed.

For unit mass of air,

Heat supplied, $Q_1 = C_p(T_3 - T_2)$

Heat rejected, $Q_2 = C_p(T_4 - T_1)$

Work done = Heat supplied − Heat rejected

$$= C_p(T_3 - T_2) - C_p(T_4 - T_1)$$

Thermal efficiency $\eta = \frac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{C_p(T_3 - T_2) - C_p(T_4 - T_1)}{C_p(T_3 - T_2)}$$

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

The η of Brayton cycle in terms of pressure ratio $r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$ & adiabatic exponent γ can be obtained as follows.

Considering isentropic process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

Considering isentropic process 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

∴ Thermal efficiency

$$\eta = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

$$= 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\boxed{\eta = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}}$$

It indicates that the thermal efficiency of Brayton cycle is a function of pressure ratio & that the η increases with the increase in pressure ratio.

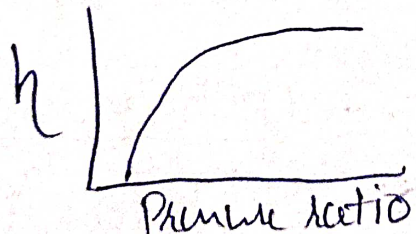


Fig 27

27. <u>Application of Gas turbines</u>

1. Aviation
2. Power generation
3. Oil & gas industry
4. Marine propulsion
5. Turbo-jet & turbo-propeller engines
6. Railway

28. [HIGHLIGHTS]

1. Any type of engine which derives heat energy from combustion of fuel or any other source & convert this, in to mechanical energy is termed as heat engine.

2. Heat engines may be classified in to to main types
(a) External Combustion Engines
(b) Internal Combustion Engines

3. The IC engines according to cycle of operation classified as 2-stroke cycle & 4-stroke cycle where as according to cycle of combustion classified as otto, diesel & dual cycle.

4. The various engine parts are cylinder, cylinder head, piston, piston rings, gudgeon pin, connecting rod, crankshaft, crank, bearings, crankcase, flywheel, governor, valve & valve mechanism etc.

5. Otto cycle is applied by A. Otto (1876). The petrol or SI engine works on this cycle with slight modification.

6. The air standard efficiency of otto cycle

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}$$

where. r = Compression ratio
γ = Adiabatic index or constant
γ for air = 1.4

7. Mean effective pressure is defined as the average pressure acting on the piston which will produce the same output as is done by the varying pressure during a cycle.

$$mep = \frac{\text{Work done per cycle}}{\text{Swept Volume}} = \frac{\text{Area of indicator loop}}{\text{length of loop}}$$

8. Mean effective pressure for otto cycle is

$$mep = \frac{p_1 r}{(\gamma-1)(r-1)} [(r^{\gamma-1}-1)(\alpha-1)]$$

where - p_1 is the pressure at point 1
r is compression ratio
γ is adiabatic constant
α - is

9. The low speed diesel engine works on a cycle which is slight modification of the Diesel cycle.

10. The air standard efficiency of diesel cycle is

$$\eta_{diesel} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{(\rho^{\gamma}-1)}{\gamma(\rho-1)}\right]$$

where r is compression ratio
γ is adiabatic index
ρ is cut-off ratio

11. Mean effective pressure for Diesel cycle is

$$mep = \frac{p_1 r}{(\gamma-1)(r-1)} [\gamma r^{\gamma-1}(\rho-1) - (\rho^{\gamma}-1)]$$

where p_1 is the pressure at point 1
r is compression ratio
ρ is cut-off ratio
γ - is adiabatic constant

12. The high speed diesel engine work on a cycle which is slight modification of Dual cycle.

13. The air standard efficiency of dual cycle is

$$\eta_{dual} = 1 - \frac{1}{r^{\gamma-1}} \left[\frac{\alpha\rho^{\gamma}-1}{(\alpha-1)+\gamma\alpha(\rho-1)}\right]$$

where r is compression ratio
ρ - is cut-off ratio
α - is explosion ratio
γ is adiabatic constant

14. Mean effective pressure for Dual cycle is

$$mep = \frac{p_1 r}{(r-1)(\gamma-1)}\left[(\alpha-1)r^{\gamma-1} + \gamma\alpha r^{\gamma-1}(\rho-1) - (\alpha\rho^{\gamma}-1)\right]$$

Where p_1 is pressure at point 1
r is compression ratio
ρ is cut-off ratio
α is explosion ratio
γ is adibatic constant

15. For the same compression ratio & same heat input

$$\eta_{otto} > \eta_{dual} > \eta_{diesel}$$

16. For the same maximum pressure & same heat input

$$\eta_{diesel} > \eta_{dual} > \eta_{otto}$$

17. For the same maximum pressure & temperature

$$\eta_{diesel} > \eta_{dual} > \eta_{otto}$$

18. In case of four stroke cycle engine, the working cycle is completed in four strokes of the piston or in two revolution of the crankshaft.

19. In case of two-stroke cycle engine, the working cycle is completed in two-strokes of the piston or in one revolution of the crankshaft.

20. One working cycle consist of suction stroke, compression stroke, power stroke & exhaust stroke.

21. The actual cycle differs from theoretical one due to time loss factor, heat loss factor & exhaust blowdown factor as major factors.

22. Gas turbines are used in power generation, marine propulsion, oil & gas industries etc.

23. The thermal efficiency of constant pressure gas turbine or Brayton cycle is given as $\eta = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}$ where r_p = Pressure ratio
γ = Adiabatic Index

29. SOME NUMERICAL PROBLEMS

(a) Otto Cycle

Problem 1 :- The bore & stroke of an engine working on the Otto cycle are 17 cm & 30 cm respectively. The clearance volume is $0.001025\ m^3$. Find the air standard efficiency of Otto cycle. Assume

$C_p = 1.004\ kJ/kg\,K$ for air
$C_v = 0.717\ kJ/kg\,K$ for air

Sol :- Given

Diameter, $d = 17$ cm
Stroke, $L = 30$ cm

Clearance Volume, $V_c = 0.001025 \times 10^6 = 1025\ cm^3$

$\therefore$ Swept volume, $V_s = \frac{\pi}{4} d^2 L$

$= \frac{\pi}{4} \times (17)^2 \times 30 = 6809\ cm^3$

Total volume of cylinder $= V_s + V_c$
$= 6809 + 1025 = 7834\ cm^3$

Compression ratio, $r = \frac{V}{V_c} = \frac{7834}{1025} = 7.64$

Adiabatic index, $\gamma = \frac{C_p}{C_v} = \frac{1.004}{0.717} = 1.4$

Air standard efficiency, $\eta = 1 - \frac{1}{r^{\gamma-1}}$

$= 1 - \frac{1}{(7.64)^{1.4-1}} = 55.7$ Ans

Problem 2 :- In an ideal Otto cycle the pressure & temperature at the beginning of compression stroke are $97\ kN/m^2$ & $40^\circ C$, respectively. The compression ratio is 7:1. The heat supplied during the cycle is 1200 kJ/kg of working fluid. Determine

(a) The maximum temperature attained in the cycle,
(b) The thermal efficiency of the cycle
(c) the work done/kg during cycle

Assume $\gamma = 1.4$ & $C_v = 0.718$ kJ/kg K

Sol :-

Given:- in fig

$r = \frac{V_1}{V_2} = 7$

$T_1 = 40° + 273 = 313$ K

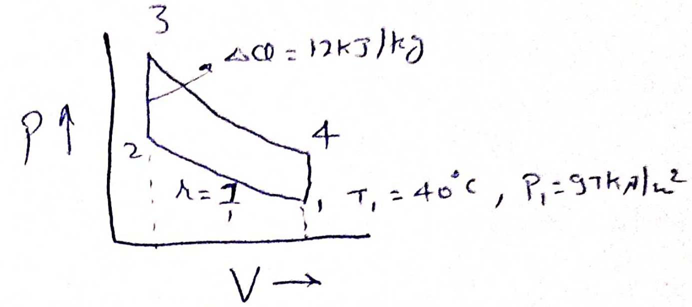


Fig. 27

(a) Process 1-2 - adiabatic process

For adiabatic process, the relation is

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\therefore \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 313\,(7)^{1.4-1} = 681.7\ K$$

For constant volume heat addition

$$\Delta Q = mC_v(T_3 - T_2)$$

$$1200 = 1 \times 0.718\,(T_3 - 681.7)$$

$$\Rightarrow \quad T_3 = 2353\ K \text{ (Max. Temp. attained)}$$ Ans

(b) $\eta = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(7)^{1.4-1}} = 54.1\%$ Ans

(c) Since, $\eta = \frac{\text{Work done}}{\text{Heat supplied}}$

$\therefore$ Work done/kg = $\eta \times$ Heat supplied/kg

$= 0.541 \times 1200$

$= 649$ kJ Ans

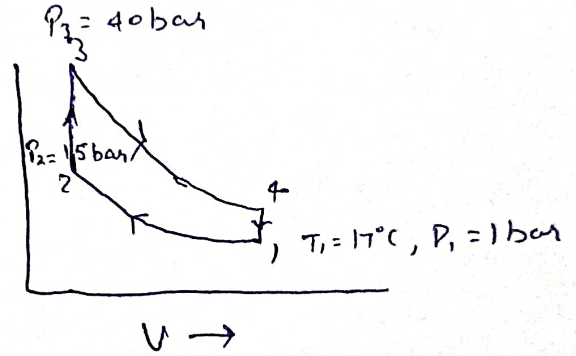
3.

Problem 3. In an constant volume ideal cycle air at 17°c & 1 bar is compressed adiabatically until the pressure is 15 bar. Heat is added at constant volume until the pressure rises to 40 bar. Calculate the air standard efficiency, the compression ratio & the mean effective pressure for the cycle.

Assume $C_v = 0.717$ kJ/kg K

$R = $ ~~8.314~~ 0.287 kJ/kg k

Solution :-



Process 1-2 (Adiabatic process)

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$$\frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{1/\gamma}$$

$$= \left(\frac{15}{1}\right)^{\frac{1}{1.4}} \quad \{\gamma \text{ for air} = 1.4\}$$

$$\therefore r = \frac{V_1}{V_2} = 6.91 \quad \text{Ans}$$

Efficiency $$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1} = 1 - \frac{1}{(6.91)^{0.4}} = 0.537$$

$$= 53.9\ \% \quad \text{Ans}$$

Also $$\frac{T_2}{T_1} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow T_2 = T_1 \times \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= (17+273) \times \left(\frac{1}{15}\right)^{\frac{1.4-1}{1.4}} = 629.5\ K$$

Process 2-3 (constant volume process)

$$\frac{T_3}{P_3} = \frac{T_2}{P_2} \Rightarrow T_3 = P_3 \times \frac{T_2}{P_2}$$

$\therefore T_3 = \frac{40}{15} \times 629.5$

$= 1678.7 K$

Hence, Heat supplied in process 2-3, $Q_s = C_v (T_3 - T_2)$

$= 0.717 (1678.7 - 629.5)$

$= 752.3 \text{ kJ/kg}$

Work done = Efficiency × heat supplied

$= .539 \times 752.3$

$= 405.5 \text{ kJ/kg}$

Mean effective pressure (mep)

$$= \frac{\text{Work done}}{\text{Swept Volume}}$$

Now, Swept volume $= V_1 - V_2$

& $V_1 = \frac{mRT_1}{P_1}$ $\{\because PV = mRT\}$

$\therefore V_1 = \frac{1 \times 0.287 \times 290}{1 \times 10^5} = 0.8314 \text{ m}^3/\text{kg}$

& $\frac{V_1}{V_2} = 6.91$

$\therefore V_2 = \frac{V_1}{6.91}$

So, $V_1 - V_2 = \frac{5.91}{6.91} \times 0.8314 = 0.711 \text{ m}^3/\text{kg}$

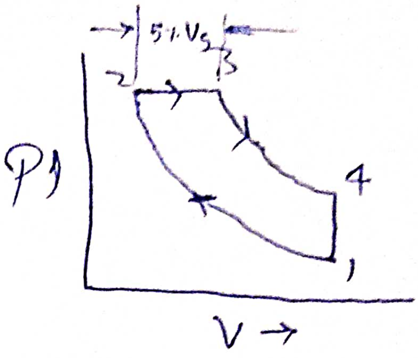
$\therefore$ Mean effective pressure (mep)

$= \frac{405.5 \times 10^3}{0.711 \text{ m}^3} = 5.7 \times 10^5 \text{ N/m}^2$

$= 5.7$ bar Ans

Problem 4:- A diesel engine has a compression ratio of 20 & cut-off takes place at 5% of the stroke. Find the air-standard efficiency. Assume $\gamma = 1.4$

Solution:-



Given

$$r = 20$$

$$\Rightarrow \frac{V_1}{V_2} = 20 \quad \text{(1)}$$

$$\& \; V_3 = V_2 + 5\% \text{ of } V_s$$
$$= V_2 + 0.05 V_s$$
$$= V_2 + 0.05 (V_1 - V_2)$$
$$= V_2 + 0.05 (20V_2 - V_2) \qquad \{\because \text{ from (1)}\}$$
$$= 1.95 V_2$$

$$\therefore \frac{V_3}{V_2} = 1.95 = \text{Cut-off ratio} = \rho$$

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

$$= 1 - \frac{1}{(20)^{1.4-1}} \left[\frac{(1.95)^{1.4} - 1}{1.4(1.95 - 1)} \right]$$

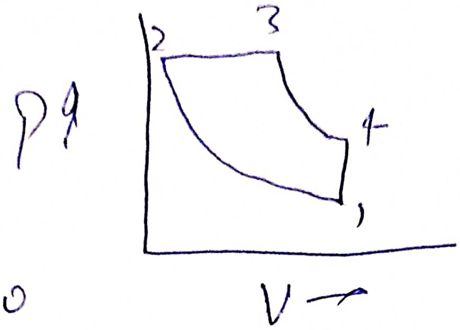
$$= 0.649$$

$$= 64.9\% \quad \text{Ans}$$

Problem 5. A diesel engine is working with a compression ratio of 15 & expansion ratio of 10. Calculate the air-standard efficiency of the cycle. Assume $\gamma = 1.4$

Sol :-

Given



Compression ratio

$$r = \frac{V_1}{V_2} = 15$$

Expansion ratio

$$r_e = \frac{V_4}{V_3} = 10$$

As Cut-off ratio $\rho = \frac{r}{r_e} = \frac{15}{10} = 1.5$

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

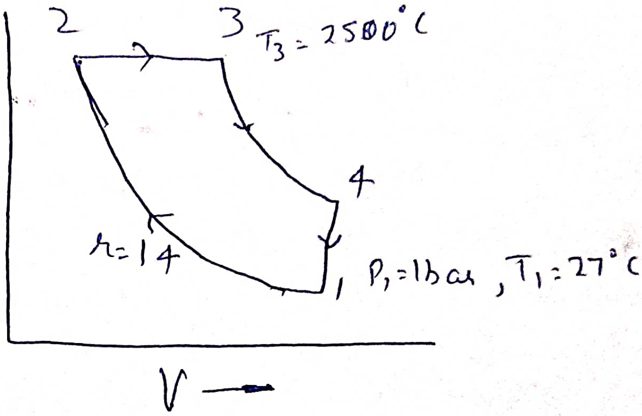
$$= 1 - \frac{1}{(15)^{1.4-1}}\left[\frac{(1.5)^{1.4}-1}{1.4(1.5-1)}\right]$$

$$= 0.63$$

$$= 63\%$$ Ans

Problem 6:- An air standard diesel cycle has a compression ratio of 14. The pressure at the beginning of the compression ratio is 1 bar & the temperature is 27°C. The maximum temperature is 2500°C. Determine the thermal efficiency & the mean effective pressure. Assume $\gamma = 1.4$

Solution:- fig



$T_1 = 27 + 273 = 300 k$

$P_1 = 1$ bar

$T_3 = 2500 + 273 = 2773 k$

$r = 14$

Process 1-2 (Adiabatic process)

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 r^{\gamma-1}$$

$$= 300 (14)^{1.4-1} = 864 k$$

$$\& \; P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = 1 \left(\frac{864}{300}\right)^{\frac{1.4}{1.4-1}} = 40.5 \text{ bar}$$

Process 2-3 (Constant Pressure Process)

$$\frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{2773}{864} = 3.21 = \beta \text{ (cut off ratio)}$$

& Process 3-4 (Adiabatic Process)

$$\therefore \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{V_4}{V_2} \times \frac{V_2}{V_3}\right)^{\gamma-1} = \left(\frac{V_1}{V_2} \times \frac{V_2}{V_3}\right)^{\gamma-1} \quad [\because V_1 = V_4]$$

$$= \left(\frac{14}{3.21}\right)^{1.4-1} = 4.36^{0.4} = 1.8$$

$$\therefore T_4 = \frac{T_3}{1.8} = \frac{2773}{1.8} = 1540 k$$

∴ Thermal efficiency, $\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$

$$= 1 - \frac{1}{14^{(1.4-1)}}\left[\frac{(3.21)^{1.4}-1}{1.4(3.21-1)}\right]$$

$$= 0.536$$

$$= 53.6\% \quad \underline{\text{Ans}}$$

For, Mean effective pressure = $\frac{\text{Net work/cycle}}{\text{Swept volume}}$

Net work done = Efficiency X Heat supplied

Heat supplied = $C_p (T_3 - T_2)$

$$= 1.005 (2773 - 864)$$

$$=$$

∴ Net work done $= 0.536 \times 1.005(2773-864) =$

Swept volume $= V_1 - V_2 = V_1\left(1 - \frac{1}{14}\right) \left\{\because \frac{V_1}{V_2} = 14\right\}$

& V_1 for 1 kg $= \frac{RT_1}{P_1} = \frac{0.287 \times 30}{10^2} = 0.861\ m^3/kg$

∴ Mean effective pressure $= \frac{0.536 \times 1.005(2773-864)}{0.861 \times \frac{13}{14}}$

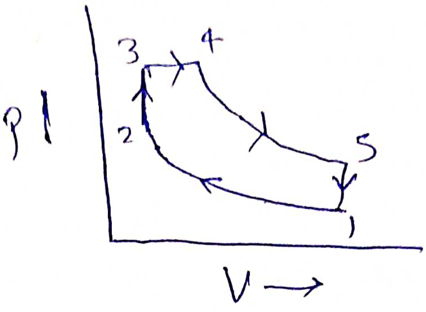
$$= 12.86 \text{ bar} \quad \underline{\text{Ans}}$$

(c) Dual cycle

Problem 7 :- An engine working on the dual combustion cycle has a compression ratio of 14 & the explosion ratio [illegible] [illegible] in 1.4 & cut-off occurred at 5% of the stroke. Find air standard efficiency.

Solution.

Given



Compression ratio

$r = \frac{V_1}{V_2} = 14$

Explosion ratio

$\alpha = \frac{P_3}{P_2} = 1.4$

cut-off ratio $\rho = \frac{V_4}{V_3}$

$V_4 = V_3 + 5\%\ V_s$

$= V_3 + 0.5 (V_1 - V_2)$

$= V_3 + 0.05 (14 V_2 - V_2)$

$= V_3 + 0.05 \times 13 V_2$

$= V_3 + 0.05 \times 13\ V_3 \quad \{\because V_2 = V_3\}$

$= V_3 \times 1.65$

$\therefore \rho = \frac{V_4}{V_3} = 1.65$

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

$$= 1 - \frac{1}{14^{1.4-1}} \left[\frac{1.4 (1.65)^{1.4} - 1}{(1.4-1) + 1.4 \times 1.4 (1.65-1)} \right]$$

$= 0.62$

$= 62\%$ Ans

Problem 8:- An air-standard Dual cycle has a compression ratio of 10. The pressure & temperature at the beginning of compression are 1 bar & 27°C. The maximum pressure reached is 42 bar & the maximum temperature is 1500°C. Determine

(i) the temperature at the end of constant volume heat addition

(ii) Cut-off ratio

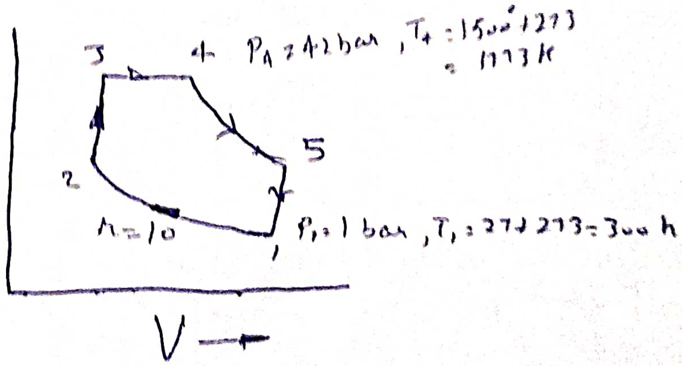
(iii) Work done per kg of air &

(iv) Thermal efficiency

Assume $C_p = 1.004$ kJ/kgK, $\gamma = 1.4$, $C_v = 0.717$ kJ/kgK

Solution :-

Compression ratio, $r = 10$



(i) Process 1-2 (Adiabatic process)

$$\frac{T_2}{T_1} = (r)^{\gamma-1}$$

$$= 10^{1.4-1} = 10^{0.4} = 2.512$$

or $T_2 = T_1 \times 2.512 = 300 \times 2.512 = 753.6$ K

& $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = r^{\gamma}$

or $P_2 = P_1 r^{\gamma} = 1 \times 10^{1.4} = 25.12$ bar

Process 2-3 (Constant volume process)

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = \frac{P_4}{P_2} \quad (\because P_3 = P_4)$$

$$\therefore T_3 = T_2 \times \frac{P_4}{P_2} = \frac{753.6 \times 42}{25.12} = 1260 \text{ K} \quad \textbf{Ans}$$

(ii) Cut-off ratio $\rho = \frac{V_4}{V_3} = \frac{T_4}{T_3} = \frac{1773}{1260} = 1.41$ Ans

(iii) Heat supplied / kg $= C_v(T_3 - T_2) + C_p(T_4 - T_3)$

$= 0.717(1260 - 753.6) + 1.004(1773 - 1260)$

$= 878.1$ kJ

For Process 4-5 (Adiabatic Process)

$$\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1} = \left(\frac{r}{\rho}\right)^{\gamma-1}$$

$$= \left(\frac{10}{1.41}\right)^{1.4-1} = 2.19$$

or $T_5 = \frac{T_4}{2.19} = \frac{1773}{2.19} = 809.2$ K

Heat rejected / kg $= C_v(T_5 - T_1)$

$= 0.717(809.2 - 300)$

$= 365.0$ kJ

Work done / kg = Heat supplied/kg − Heat rejected/kg

$= 878.1 - 365.0$

$= 513.1$ kJ

(iv) $\eta_{Dual} = \frac{\text{Work done/kg}}{\text{Heat supplied/kg}}$

$= \frac{513.1}{878.1} = 0.584$

$= 58.4\%$ Ans

11

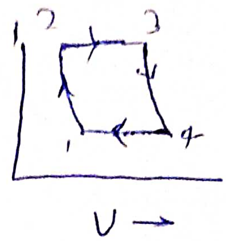
(d) Brayton or Joule cycle

Problem 9 :- In a gas turbine air is drawn in at 1.02 bar & 15°C & is compressed to 6.12 bar. Calculate thermal efficiency. Take $\gamma = 1.4$ & $C_p = 1.005$ kJ/kgK

Sol :-

$P_1 = 1.02$ bar

$P_2 = 6.12$ bar



Pressure ratio $= \frac{P_2}{P_1} = \frac{6.12}{1.02}$

Thermal efficiency $\eta = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}$

$= 1 - \frac{1}{\left(\frac{6.12}{1.02}\right)^{\frac{1.4-1}{1.4}}} = 0.403$

$= 40.3\%$ Ans

Problem 10 :- In a constant pressure gas turbine cycle, the air enters the compressor at 300K & 100×10^3 N/m². The pressure ratio is 10 & the maximum temperature is 1350 K. Determine

(i) The pressure & temperature at each state in the cycle

(ii) Compressor work

(iii) Turbine output

(v) Efficiency

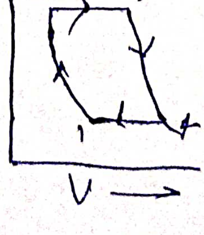
Assume $\gamma = 1.4$

Solution :-

$P_1 = 100 \times 10^3$ N/m²

$T_1 = 300$ K

$r_p = \frac{P_2}{P_1} = 10$



$\therefore P_2 = P_1 \times 10 = 100 \times 10^3 \times 10 = 1 \times 10^6$ N/m² Ans

Process 1-2 (Adiabatic process)

$\therefore \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$= (10)^{\frac{1.4-1}{1.4}} = 1.93$

$\Rightarrow T_2 = T_1 \times 1.93$

$= 300 \times 1.93 = 579\,K$ Ans

Now, $P_3 = P_2 = 1 \times 10^5\,N/m^2$

Process 3-4 (Adiabatic Process)

$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$

$\Rightarrow T_4 = T_3 \left(\frac{P_1}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$ $\{\because P_2 = P_3 \;\&\; P_1 = P_4\}$

$\Rightarrow T_4 = 1350 \left(\frac{100 \times 10^3}{10^6}\right)^{\frac{1.4-1}{1.4}}$

$= 1350 \times 0.52 = 698\,K$ Ans

(ii) Compressor Work $= C_p(T_2 - T_1)$

$= 1.005(579 - 300)$

$= 280.3\,kJ/kg$

(iii) Turbine Work $= C_p(T_3 - T_4)$

$= 1.005(1350 - 698)$

$= 655.2\,kJ/kg$

(v) Efficiency, $\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$

$= 1 - \frac{1}{(10)^{\frac{1.4-1}{1.4}}} = 0.483$

$= 48.3\%$ Ans

30. EXERCISE

(a) Theoritical Questions

1. Differentiate between external & internal combustion engines.

2. Explain the following terms:

(a) Bore
(b) Stroke length
(c) Compression ratio
(d) Cut-off ratio
(e) Explosion ratio
(f) Expansion ratio
(g) Clearance volume
(h) Swept or Stroke volume
(i) Mean effective pressure
(j) Thermal efficiency
(k) TDC
(l) BDC

3. Explain the classification of IC engines.

4. State the functions of following parts with neat sketches
Spark plug, Piston rings, valve & valve mechanism, Crank & crankshaft, flywheel

5. Sketch the otto-cycle on P-V diagram & explain all its processes.

6. Drive an expression for the efficiency of Otto cycle & comment on the effect of compression ratio on the efficiency with respect of ratio of specific heats (γ) by means of graph.

7. Drive an expression for mean effective pressure of an Otto cycle.

8. Sketch the Diesel cycle on P-V & T-S diagram & explain its various processes.

9. What is the basic difference between an Otto & Diesel cycle? Drive the expression for the efficiency & mean effective pressure of Diesel cycle.

10. Sketch the P-V & T-S diagram of a Dual cycle. Why this cycle is also called limited pressure or mixed cycle?

11. Obtain an expression for the efficiency & mean effective pressure of a Dual cycle.

12. Compare Otto, Diesel & Dual cycle for the
   (i) Same compression ratio & same heat input
   (ii) Same maximum pressure & same heat input
   (iii) Same heat rejection.

13. Where do the following cycles have applications
   (i) Otto cycle
   (ii) Diesel cycle
   (iii) Dual cycle
   (iv) Brayton cycle

14. Explain the construction, working & applications of 4-stroke SI engine.

15. Explain the construction, working & applications of 4-stroke CI engine.

16. Explain the construction, working & applications of 4-stroke & 2-stroke SI & CI engine.

17. Explain how actual indicator (P-V) diagram is different from theoritical indicator (P-V) diagram in case of 4-stroke diesel engine.

18. Compare two-stroke & four-stroke cycle engines.

19. Compare SI & CI engine on the basis of
(a) Basic cycle
(b) Compression ratio
(c) Fuel used
(d) Induction of fuel
(e) Ignition
(f) Thermal efficiency
(g) Weight
(h) Cost

20. Derive an expression for efficiency of Brayton cycle & also explain all its processes & applications.

21. What are the basic components of a gas turbine plant? Discuss the air standard cycle for such a plant.

22. State the merits & demerits of gas turbines.

(b) Numerical Problems

1. An engine working on Otto cycle has the following conditions: Pressure at the beginning of compression is 1 bar & pressure at the end of compression is 11 bar. Calculate the compression ratio & air standard efficiency. Assume $\gamma_{air} = 1.4$

[Ans Compression ratio = 5.54
η = 49.6%]

2. A gas engine working on the Otto cycle has a cylinder of diameter 200mm & stroke 250 mm. The clearance volume is 1570 cm^3. Find the air standard efficiency $\gamma = 1.4$

[Ans η = 51.2%]

3. An engine working on the Otto cycle with compression ratio 5.5 & the pressure & temperature at the beginning of compression are 1 bar & 27° C respectively. The peak pressure is 30 bar. Determine the air standard efficiency & the mean effective pressure. $\gamma = 1.4$ [Ans: η = 49.43% & mep = 5.24 bar

2..

4. A diesel engine having a cylinder with bore 250mm, stroke 375 mm & a clearance volume of 1500 cm^3, with cut-off occuring at 5% of the stroke. Assume $\gamma = 1.4$ for air. Determine its efficiency.

[Ans: $\eta = 60.52\%$.]

5. In an engine working on Diesel cycle inlet pressure & temperature are 1 bar & 17°C respectively. Expansion ratio is 5 & pressure at the end of adiabatic compression is 35 bar. Calculate the heat addition & efficiency of cycle. $\gamma = 1.4$ [Ans: $Q_s = 1235.5$ kJ/kg, $\eta = 54.9\%$.]

6. A high speed diesel engine working on ideal dual combustion cycle takes in air at a pressure of 1 bar & temperature of 50°C & compresses it adiabatically to $\frac{1}{14}$th of its original volume. At the end of the compression the heat is added in such a manner that during the first stage the pressure increases at constant volume to twice the pressure of the adiabatic compression, & during second stage following the constant volume addition, the volume is increased twice the clearance volume at constant pressure. The air is then allowed to expand adiabatically to the end of the stroke where it is exhausted, heat being rejected at constant volume. Calculate the thermal efficiency. [Ans: $\eta = 60.8\%$.]

7. An engine having a compression ratio of 15:1 operates on the ideal dual combustion cycle. At the begining of compression the air in the cylinder at 0.986 bar & 21°C. After compression the heat

energy is supplied at constant volume increases the temperature to 1100°C, & the heat energy supplied at constant pressure take place over 4% of the stroke. Calculate the maximum pressure, the maximum temperature & cycle efficiency. [Ans. $P = 69.1$ bar, $T = 1870°C$, $\eta = 63.4\%$]

8. A power plant operating on Brayton cycle has a pressure ratio of 6 to 1. The maximum & minimum temperatures are 1000°C & 20°C respectively. Calculate air standard efficiency $\gamma = 1.4$, $C_p = 1.005$ kJ/kgK [Ans. $\eta = 40\%$]

31. OBJECTIVE TYPE QUESTIONS

1. Compression ratio of I.C. engines is
(a) Volume displaced by piston per stroke & clearance volume in cylinder
(b) Ratio of pressure after compression & before compression
(c) the ratio of volumes of air in cylinder before compression stroke & after compression stroke
(d) Swept volume/ cylinder volume.

2. The working cycle in case of four stroke engine is completed in following number of revolution of crankshaft
(a) $1/2$ (b) 1
(c) 2 (d) 4

3. Air standard Otto cycle efficiency is expressed as
(a) $1-\left(\frac{1}{r}\right)^{\frac{\gamma-1}{\gamma}}$ (b) $1-\left(\frac{1}{r}\right)^{\frac{\gamma}{\gamma-1}}$
(c) $1-\left(\frac{1}{r}\right)^{\gamma-1}$ (d) $1-\left(\frac{1}{r}\right)^{\gamma+1}$

4. Most high speed diesel engines operate on
(a) Otto cycle (b) Diesel cycle
(c) Dual cycle (d) Carnot cycle

5. The air standard efficiency of an Otto cycle compared to diesel cycle for the given compression ratio is
(a) Same (b) Less
(c) More (d) More or less depending upon other factors.

6. Which of the following is not an internal combustion engine

(a) Steam Turbine (b) 2-stroke petrol engine

(c) 4-stroke petrol engine (d) Diesel engine

7. Pick up the wrong statement

(a) In 4-stroke engine, a power stroke is obtained in 4-strokes

(b) Petrol engines work on Otto cycle.

(c) Petrol engines occupy more space than diesel engines for same power output.

(d) 2-stroke engines cause more pollution.

8. In a diesel engine, the fuel is ignited by

(a) Spark plug (b) injected fuel

(c) heat resulting from compressing air that is supplied for combustion.

(d) Current

9. Pick-up the wrong statement

(a) A two-stroke engine has no valves.

(b) I.C engines have higher efficiency than steam engines.

(c) Heavy oils engines works on diesel cycle.

(d) Gas engine works on Otto cycle.

10. In diesel engine, the compression ratio in comparison to expansion ratio is

(a) Same (b) less

(c) Variable (d) More

11. Engine pistons are usually made of aluminium alloy because it

(a) is stronger (b) is lighter

(c) wears less (d) is heavier

12. The thermal efficiency of a two-stroke cycle engine as compared to four stroke cycle engine is
(a) less
(b) same
(c) more
(d) depending upon other factors

13. The compression ratio for a petrol engine varies from
(a) 25 to 40
(b) 10 to 15
(c) 6 to 10
(d) 15 to 25

14. Carburetor is used for a
(a) SI engine
(b) CI engine
(c) Gas turbine
(d) Steam engine

15. In a diesel engine, during suction stroke
(a) Air-fuel mixture enters inside the cylinder
(b) Only air enters inside the cylinder
(c) Only fuel enters inside the cylinder
(d) None of above

16.

Ans 1. (c) 2. (d) 3. (c) 4. (c) 5. (c)
6. (a) 7 (c) 8 (c) 9 (d) 10 (d) 11 (b)
12. (a) 13 (c) 14 (a) 15 (b)