

INTERNAL COMBUSTION ENGINE & GAS TURBINES

Module - I

INTRODUCTION

Heat engine:

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types-

- (a) External combustion engine
- (b) Internal combustion engine

External combustion engine:

In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle.

Examples:

*In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work.

*In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.

Internal combustion engine:

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force. It can be classified into the following types:

1. According to the basic engine design- (a) Reciprocating engine (Use of cylinder piston arrangement), (b) Rotary engine (Use of turbine)
2. According to the type of fuel used- (a) Petrol engine, (b) diesel engine, (c) gas engine (CNG, LPG), (d) Alcohol engine (ethanol, methanol etc)
3. According to the number of strokes per cycle- (a) Four stroke and (b) Two stroke engine
4. According to the method of igniting the fuel- (a) Spark ignition engine, (b) compression ignition engine and (c) hot spot ignition engine
5. According to the working cycle- (a) Otto cycle (constant volume cycle) engine, (b) diesel cycle (constant pressure cycle) engine, (c) dual combustion cycle (semi diesel cycle) engine.

6. According to the fuel supply and mixture preparation- (a) Carburetted type (fuel supplied through the carburettor), (b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition).
7. According to the number of cylinder- (a) Single cylinder and (b) multi-cylinder engine
8. Method of cooling- water cooled or air cooled
9. Speed of the engine- Slow speed, medium speed and high speed engine
10. Cylinder arrangement-Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines.
11. Valve or port design and location- Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging.
12. Method governing- Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine
14. Application- Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators.

Comparison between external combustion engine and internal combustion engine:

External combustion engine	Internal combustion engine
*Combustion of air-fuel is outside the engine cylinder (in a boiler)	* Combustion of air-fuel is inside the engine cylinder (in a boiler)
*The engines are running smoothly and silently due to outside combustion	* Very noisy operated engine
*Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome.	* It is light and compact due to lower ratio of weight and bulk to output.
*Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts.	* Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used
*It can use cheaper fuels including solid fuels	*High grade fuels are used with proper filtration
*Lower efficiency about 15-20%	*Higher efficiency about 35-40%
* Higher requirement of water for dissipation of energy through cooling system	*Lesser requirement of water
*High starting torque	*IC engines are not self-starting

Main components of reciprocating IC engines:

Cylinder: It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above

2000 °C. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Cylinder head: The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint.

Piston: Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminium alloy which has good heat conducting property and greater strength at higher temperature.

Figure 1 shows the different components of IC engine.

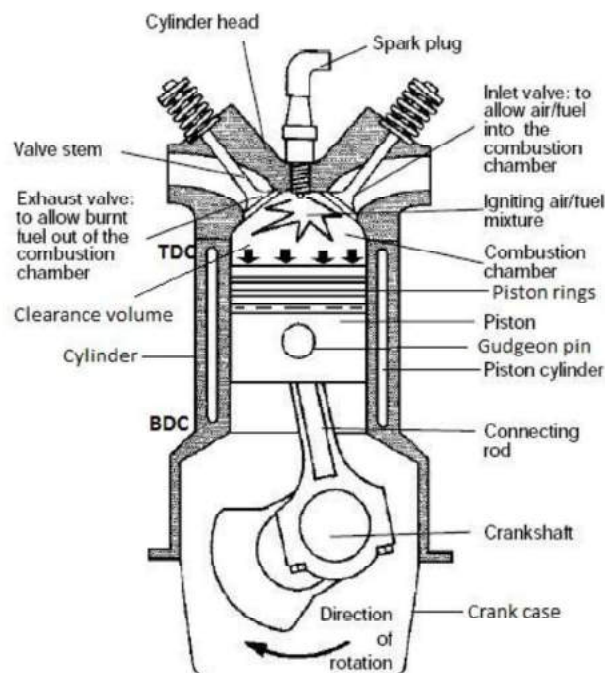


Fig. 1. Different parts of IC engine

Piston rings: These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature. 2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

Connecting rod: It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank

with crank pin. The special steel alloys or aluminium alloys are used for the manufacture of connecting rod.

Crankshaft: It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Crank case: It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.

Flywheel: It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant. It is done by storing excess energy during the power stroke, which is returned during other stroke.

Terminology used in IC engine:

1. Cylinder bore (D): The nominal inner diameter of the working cylinder.
2. Piston area (A): The area of circle of diameter equal to the cylinder bore.
3. Stroke (L): The nominal distance through which a working piston moves between two successive reversals of its direction of motion.
4. Dead centre: The position of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).
 - (a) Bottom dead centre (BDC): Dead centre when the piston is nearest to the crankshaft.
 - (b) Top dead centre (TDC): Dead centre when the position is farthest from the crankshaft.
5. Displacement volume or swept volume (V_s): The nominal volume generated by the working piston when travelling from the one dead centre to next one and given as,

$$V_s = A \times L$$

6. Clearance volume (V_c): the nominal volume of the space on the combustion side of the piston at the top dead centre.

7. Cylinder volume (V): Total volume of the cylinder.

$$V = V_s + V_c$$

8. Compression ratio (r): $r = \frac{V_s}{V_c}$

Four stroke engine:

- Cycle of operation completed in four strokes of the piston or two revolution of the piston.

- (i) Suction stroke (suction valve open, exhaust valve closed)-charge consisting of fresh air mixed with the fuel is drawn into the cylinder due to the vacuum pressure created by the movement of the piston from TDC to BDC.
- (ii) Compression stroke (both valves closed)-fresh charge is compressed into clearance volume by the return stroke of the piston and ignited by the spark for combustion. Hence pressure and temperature is increased due to the combustion of fuel
- (iii) Expansion stroke (both valves closed)-high pressure of the burnt gases force the piston towards BDC and hence power is obtained at the crankshaft.
- (iv) Exhaust stroke (exhaust valve open, suction valve closed)- burned gases expel out due to the movement of piston from BDC to TDC.

Figure 2 show the cycle of operation of four stroke engine.

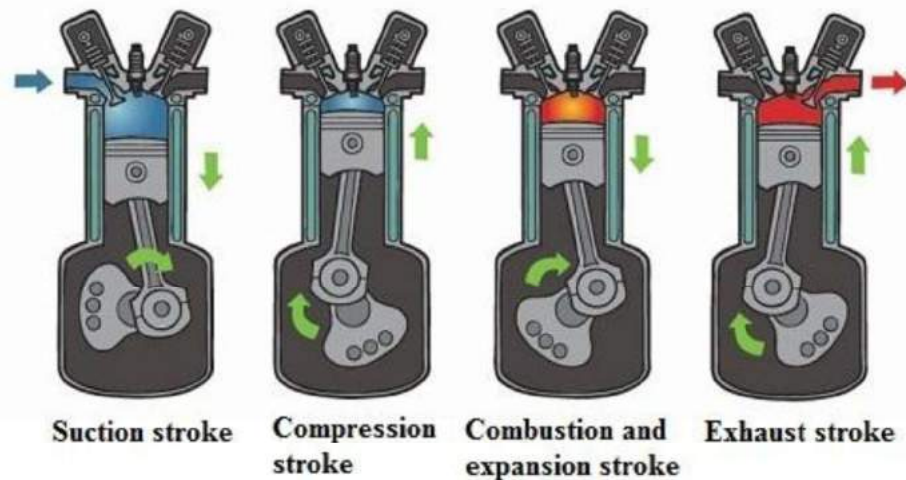


Fig. 2. Cycle of operation in four stroke engine

Two stroke engine:

- No piston stroke for suction and exhaust operations
- Suction is accomplished by air compressed in crankcase or by a blower
- Induction of compressed air removes the products of combustion through exhaust ports
- Transfer port is there to supply the fresh charge into combustion chamber

Figure 3 represents operation of two stroke engine

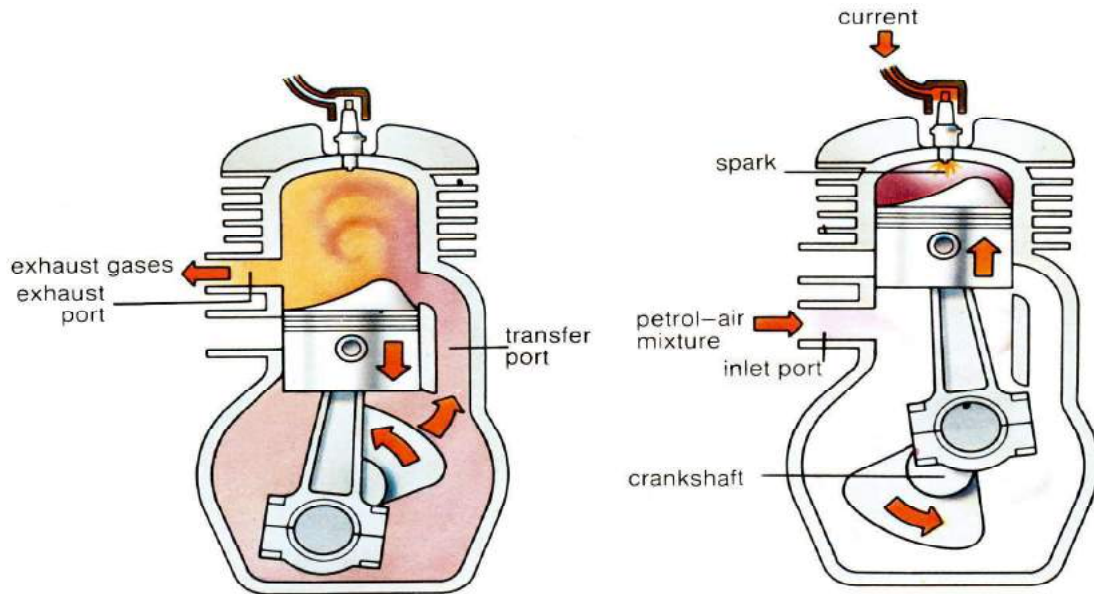


Fig. 3. Cycle of operation in two stroke engine

Comparison of Four-stroke and two-stroke engine:

Four-stroke engine	Two-stroke engine
1. Four stroke of the piston and two revolution of crankshaft	Two stroke of the piston and one revolution of crankshaft
2. One power stroke in every two revolution of crankshaft	One power stroke in each revolution of crankshaft
3. Heavier flywheel due to non-uniform turning movement	Lighter flywheel due to more uniform turning movement
4. Power produce is less	Theoretically power produce is twice than the four stroke engine for same size
5. Heavy and bulky	Light and compact
6. Lesser cooling and lubrication requirements	Greater cooling and lubrication requirements
7. Lesser rate of wear and tear	Higher rate of wear and tear
8. Contains valve and valve mechanism	Contains ports arrangement
9. Higher initial cost	Cheaper initial cost
10. Volumetric efficiency is more due to greater time of induction	Volumetric efficiency less due to lesser time of induction
11. Thermal efficiency is high and also part load efficiency better	Thermal efficiency is low, part load efficiency lesser
12. It is used where efficiency is important.	It is used where low cost, compactness and light weight are important.
Ex-cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.	Ex-lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc.

Comparison of SI and CI engine:

SI engine	CI engine
Working cycle is Otto cycle.	Working cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
High self-ignition temperature.	Low self-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Use of spark plug for ignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Higher maximum RPM due to lower weight	Lower maximum RPM
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavier due to higher pressures

Valve timing diagram:

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Fig. 4.

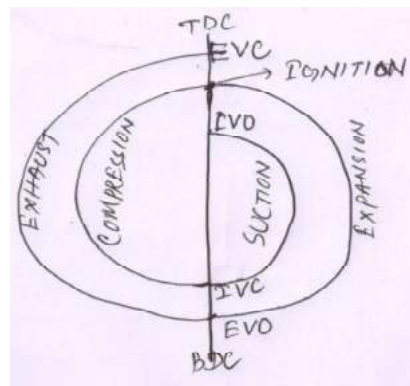


Fig. 4. Theoretical valve timing diagram

But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

Opening and closing of inlet valve

-Inlet valve opens 12 to 30° CA before TDC to facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

-Inlet valve closes 10-60° CA after TDC due to inertia movement of fresh charge into cylinder i.e. ram effect.

Figure 5 represents the actual valve timing diagram for low and high speed engine.

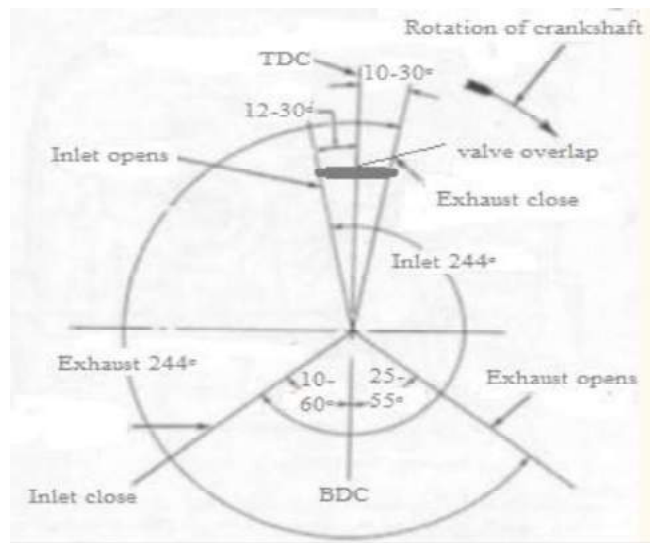


Fig. 5. Actual valve timing diagram for low and high speed engine

Opening and closing of exhaust valve

Exhaust valve opens 25 to 55° CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30° CA after TDC to avoid the compression of burnt gases in next cycle. Kinetic energy of the burnt gas can assist maximum exhausting of the gas. It also increases the volumetric efficiency.

Note: For low and high speed engine, the lower and upper values are used respectively

Valve overlap

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.

Port timing diagram:

-Drawn for 2-stroke engine

-No valve arrangement

-3 ports- inlet, transfer and exhaust

Figure 6 shows port timing diagram for 2-stroke engine

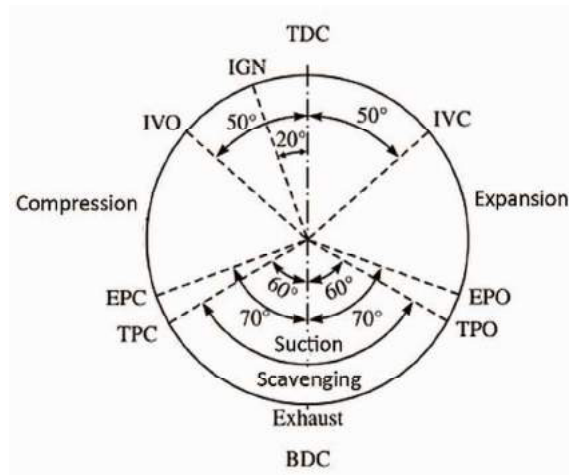


Fig. 6. Port timing diagram for 2-stroke engine

Working cycle:

(a) **Otto cycle**- thermodynamic cycle for SI/petrol engine

-Reversible adiabatic compression and expansion process

-Constant volume heat addition (combustion) and heat rejection process (exhaust)

Figure 7 depicts the Otto cycle

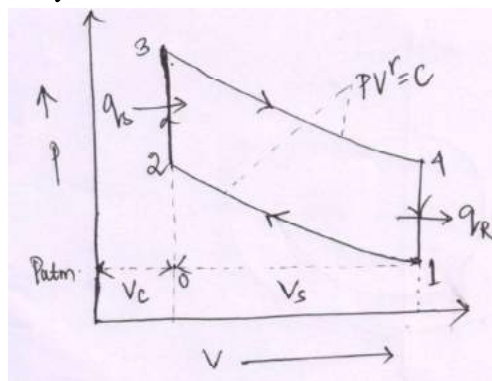


Fig. 7. Otto cycle

Heat supplied, $q_s = C_v(T_3 - T_2)$

Heat rejection, $q_R = C_v(T_4 - T_1)$

Compression ratio, $r_k = \frac{V_1}{V_2}$

Thermal efficiency, $\eta_{th} = \frac{q_s - q_R}{q_s} = \frac{C_v(T_3 - T_2) - C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$

In process 1-2, adiabatic compression process,

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

$$\Rightarrow T_2 = T_1 \cdot (r_k)^{\gamma-1}$$

In adiabatic expansion process, i.e. 3-4,

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

$$\Rightarrow T_3 = T_4 \cdot (r_k)^{\gamma-1}$$

$$\begin{aligned} \eta_{th} &= 1 - \frac{T_4 - T_1}{T_4 \cdot (r_k)^{\gamma-1} - T_1 \cdot (r_k)^{\gamma-1}} \\ &= 1 - \frac{1}{(r_k)^{\gamma-1}} \end{aligned}$$

Work done (W)

$$\text{Pressure ratio, } r_p = \frac{P_3}{P_2} = \frac{P_4}{P_1}$$

$$\frac{P_2}{P_1} = \frac{P_3}{P_4} = \left(\frac{V_1}{V_2}\right)^\gamma = (r_k)^\gamma$$

$$\begin{aligned} W &= \frac{P_3 V_3 - P_4 V_4}{\gamma - 1} - \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} \\ &= \frac{1}{\gamma - 1} \left[P_4 V_4 \left(\frac{P_3 V_3}{P_4 V_4} - 1 \right) - P_1 V_1 \left(\frac{P_2 V_2}{P_1 V_1} - 1 \right) \right] \\ &= \frac{1}{\gamma - 1} [P_4 V_1 (r_k^{\gamma-1} - 1) - P_1 V_1 (r_k^{\gamma-1} - 1)] \\ &= \frac{P_1 V_1}{\gamma - 1} [r_p (r_k^{\gamma-1} - 1) - (r_k^{\gamma-1} - 1)] \\ &= \frac{P_1 V_1}{\gamma - 1} [(r_k^{\gamma-1} - 1)(r_p - 1)] \end{aligned}$$

$$\text{Mean effective pressure, } P_m = \frac{\text{work done}}{\text{Swept volume}} = \frac{\text{work done}}{V_1 - V_2}$$

$$P_m = \frac{\frac{P_1 V_1}{\gamma - 1} [(r_k^{\gamma-1} - 1)(r_p - 1)]}{V_1 - V_2} = \frac{P_1 r_k [(r_k^{\gamma-1} - 1)(r_p - 1)]}{(\gamma - 1)(r_k - 1)}$$

(b) **Diesel cycle**- thermodynamic cycle for low speed CI/diesel engine

-Reversible adiabatic compression and expansion process

-Constant pressure heat addition (combustion) and heat rejection process (exhaust)

Figure 8 depicts the diesel cycle.

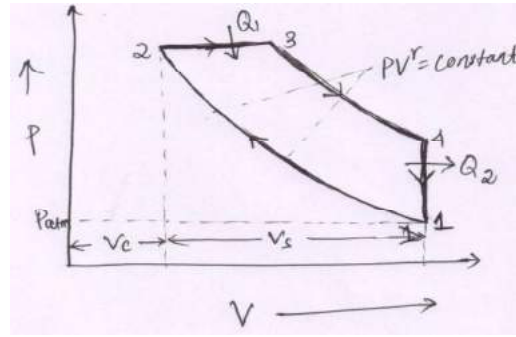


Fig. 8. Diesel cycle

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

Heat rejection, $Q_2 = C_v(T_4 - T_1)$

Compression ratio, $r_k = \frac{V_1}{V_2}$

Cut off ratio, $r_c = \frac{V_3}{V_2}$

Thermal efficiency, $\eta_{th} = \frac{Q_1 - Q_2}{Q_1} = \frac{C_p(T_3 - T_2) - C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{1}{\gamma} \frac{(T_4 - T_1)}{(T_3 - T_2)}$

In adiabatic compression process i.e. 1-2,

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

$$\Rightarrow T_2 = T_1 \cdot (r_k)^{\gamma-1}$$

In process 2-3, pressure constant, then

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = r_c$$

$$\Rightarrow T_3 = T_2 \cdot r_c = T_1 \cdot (r_k)^{\gamma-1} \cdot r_c$$

In adiabatic expansion process i.e. 3-4,

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_2} \cdot \frac{V_2}{V_4}\right)^{\gamma-1} = (r_c)^{\gamma-1} \cdot \frac{1}{(r_k)^{\gamma-1}}$$

$$\Rightarrow T_4 = T_3 \cdot (r_c)^{\gamma-1} \cdot \frac{1}{(r_k)^{\gamma-1}} = T_1 \cdot (r_k)^{\gamma-1} \cdot r_c \cdot (r_c)^{\gamma-1} \cdot \frac{1}{(r_k)^{\gamma-1}} = T_1 \cdot r_c$$

$$\eta_{th} = 1 - \frac{1}{\gamma} \frac{(T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{1}{\gamma \cdot (r_k)^{\gamma-1}} \left[\frac{(r_c)^{\gamma} - 1}{r_c - 1} \right]$$

Work done (W)

$$W = P_2(V_3 - V_2) + \frac{P_3 V_3 - P_4 V_4}{\gamma - 1} - \frac{P_2 V_2 - P_1 V_1}{\gamma - 1}$$

$$= P_2(r_c V_2 - V_2) + \frac{P_2 r_c V_2 - P_4 r_k V_2}{\gamma - 1} - \frac{P_2 V_2 - P_1 r_k V_2}{\gamma - 1}$$

since $V_4 = V_1$

$$= P_2 V_2 \left[\frac{(r_c - 1)(\gamma - 1) + (r_c - r_c^\gamma \cdot r_k^{-\gamma} \cdot r_k) - (1 - r_k^{1-\gamma})}{\gamma - 1} \right]$$

$$= P_1 V_1 \cdot r_k^{\gamma-1} \left[\frac{\gamma(r_c - 1) - r_k^{1-\gamma}(r_c^\gamma - 1)}{\gamma - 1} \right]$$

Mean effective pressure,

$$P_m = \frac{P_1 V_1 r_k^{\gamma-1} \left[\frac{\gamma(r_c-1) - r_k^{1-\gamma} (r_c^\gamma - 1)}{\gamma-1} \right]}{V_1 - V_2} = \frac{P_1 r_k^\gamma [\gamma(r_c-1) - r_k^{1-\gamma} (r_c^\gamma - 1)]}{(\gamma-1)(r_k-1)}$$

(c) Dual cycle or limited pressure cycle-thermodynamic cycle for high speed diesel and hot spot ignition engine

- Reversible adiabatic compression and expansion process
- Constant pressure and constant volume heat addition (combustion) and heat rejection process

Total heat supplied, $Q_1 = C_v(T_3 - T_2) + C_p(T_4 - T_3)$

Heat rejection, $Q_2 = C_v(T_5 - T_1)$

Compression ratio, $r_k = \frac{V_1}{V_2}$

Cut off ratio, $r_c = \frac{V_4}{V_3}$

Pressure ratio, $r_p = \frac{P_3}{P_2}$

Figure 9 shows the P-V diagram of Dual cycle.

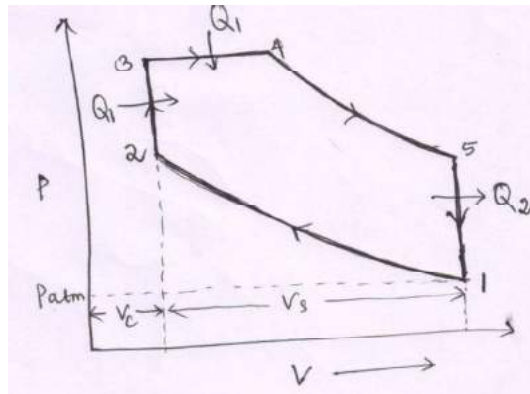


Fig. 9. Dual cycle

$$\text{Thermal efficiency, } \eta_{th} = \frac{Q_1 - Q_2}{Q_1} = \frac{C_v(T_3 - T_2) + C_p(T_4 - T_3) - C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)} = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)}$$

In adiabatic compression process i.e. 1-2,

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

In constant volume combustion process i.e. 2-3,

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

$$\Rightarrow T_2 = \frac{T_3}{r_p}$$

In constant pressure combustion process i.e. 3-4,

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

$$\Rightarrow T_4 = T_3 \cdot r_c$$

In adiabatic expansion process i.e. 4-5,

$$\frac{T_4}{T_5} = \left(\frac{V_5}{V_4}\right)^{\gamma-1} = \left(\frac{V_1}{V_4}\right)^{\gamma-1} = \left(\frac{r_k}{r_c}\right)^{\gamma-1}$$

$$\Rightarrow T_5 = r_c \cdot T_3 \cdot \left(\frac{r_c}{r_k}\right)^{\gamma-1}$$

$$\eta_{th} = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} = 1 - \frac{1}{(r_k)^{\gamma-1}} \left[\frac{r_p \cdot (r_c)^{\gamma-1}}{(r_p - 1) + \gamma r_p (r_c - 1)} \right]$$

Work done (W)

$$\begin{aligned} W &= P_3(V_4 - V_3) + \frac{P_4 V_4 - P_5 V_5}{\gamma - 1} - \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} \\ &= P_3 V_3 (r_c - 1) + \frac{(P_4 r_c V_3 - P_5 r_k V_3) - (P_2 V_3 - P_1 r_k V_3)}{\gamma - 1} \\ &= \frac{P_1 V_1 \cdot r_k^{\gamma-1} [\gamma r_p (r_c - 1) + (r_p - 1) - r_k^{\gamma-1} (r_p r_c^\gamma - 1)]}{\gamma - 1} \end{aligned}$$

Mean effective pressure,

$$\begin{aligned} P_m &= \frac{\frac{P_1 V_1 \cdot r_k^{\gamma-1} [\gamma r_p (r_c - 1) + (r_p - 1) - r_k^{\gamma-1} (r_p r_c^\gamma - 1)]}{\gamma - 1}}{V_1 - V_2} \\ &= \frac{P_1 r_k^\gamma [\gamma r_p (r_c - 1) + (r_p - 1) - r_k^{1-\gamma} (r_p r_c^\gamma - 1)]}{(\gamma - 1)(r_k - 1)} \end{aligned}$$

Comparison of Otto, Diesel and Dual cycle:

(a) For same compression ratio and same heat input

$$(\eta_{th})_{Otto} > (\eta_{th})_{Dual} > (\eta_{th})_{Diesel}$$

(b) For constant maximum pressure and same heat input

$$(\eta_{th})_{Diesel} > (\eta_{th})_{Dual} > (\eta_{th})_{Otto}$$

(c) For same maximum pressure and temperature

$$(\eta_{th})_{Diesel} > (\eta_{th})_{Dual} > (\eta_{th})_{Otto}$$

(d) For same maximum pressure and output

$$(\eta_{th})_{Diesel} > (\eta_{th})_{Otto}$$

FUELS & FUEL INJECTION

In IC engines, the chemical energy contained in the fuel is converted into mechanical power by burning (oxidizing) the fuel inside the combustion chamber of the engine.

Fuels suitable for fast chemical reaction have to be used in IC engines, they are following types-

(a) Hydrocarbons fuels derived from the crude petroleum by proper refining process such as thermal and catalytic cracking method, polymerisation, alkylation, isomerisation, reforming and blending.

(b) Alternative fuels such as-Alcohols (methanol, ethanol)

Natural gas (methane)

LPG (propane, butane)

Hydrogen

***Classification of petroleum fuels used for IC engine:**

Liquid hydrocarbons- Engine fuels are mainly mixtures of hydrocarbons, with bonds between hydrogen and carbon atoms. During combustion these bonds are broken and new bonds are formed with oxygen atoms, accompanied by the release of chemical energy. Principal products are carbon dioxide and water vapour. Fuels also contain small amounts of S, O₂, N₂, H₂O. The different constituents of crude petroleum which are available in liquid hydrocarbons are- paraffins, naphthenes, naphthenes, olefins, aromatics.

(i) Paraffin-

-Paraffins or alkanes can in general be represented by-C_nH_{2n+2}

-All the carbon bonds are single bonds – they are “saturated” high number of H atoms, high heat content and low density (620 – 770 kg/m³)

-The carbon atoms can be arranged as a straight chain or as branched chain compounds.

-Straight chain group (normal paraffins)

- shorter the chain, stronger the bond
- not suitable for SI engines – high tendency for autoignition according to the value of “n” in the formula, they are in gaseous (1 to 4), liquid (5 to 15) or solid (>16) state.