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Advanced IC Engine

Course Code: 23BTMEL306

B. Tech - V Semester

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Teaching and Evaluation Scheme

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Course Title: Advanced IC Engine										
Semester	V	Teaching Scheme				Evaluation Scheme				
						Theory			Practical	
Term	Odd	Th	Tu	Pr	Credits	TAE	CAE	ESE	INT	EXT
Course Category	PEC1	3Hrs	-	2Hrs	04	10	15	50	25	-
Course Code	23BTMEL306 23BTMEP306									
Teaching Mode	Offline	5 Hrs.			Total	75			25	
Duration of ESE	2.5 Hrs.					100				

Course Objectives and Outcomes

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Course Objectives	1. To understand the underlying principles of operation of different IC Engines and components.
	2. To provide knowledge on pollutant formation, control, alternate fuel etc.
	3. Learning about the fundamental concepts and principles that govern the design and operation of IC engines
	4. Performing thermodynamic and combustion analyses of IC engines
Course Outcomes	Upon successful completion of this course, student shall be able to:
	CO 1. Compare the operations of different IC Engine and components
	CO 2. Evaluate the pollutant formation, control, and alternate fuel.
	CO 3. Identify harmful IC engine emissions and use.
	CO 4. Analyze the viable alternative fuels in engines.
	CO 5. Analyze the pollutant formation and control.

Mapping of Course Outcomes with Program Outcomes and Program Specific Outcomes:

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Following mapping is only for reference

Course Outcomes	Program Outcomes and Program Specific Outcomes														
	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO 1	PSO 2	PSO3
CO1	3	3	3	3	1	2	--	1	1	--	--	2	2	3	--
CO2	3	3	3	3	1	2	--	1	3	--	1	2	2	3	--
CO3	3	3	3	3	1	2	--	1	2	--	--	2	2	3	--
CO4	3	3	3	3	2	2	--	1	3	--	1	2	2	3	1
CO5	3	3	3	3	2	2	--	1	3	--	1	2	2	3	1

Syllabus

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Unit	Contents
Unit 1	**Introduction to Engine** Engine Classification, Constructional Details and working principle of Spark Ignition (SI) and Compression Ignition (CI) Engines. Air Standard Cycles- Otto, Diesel and Dual. Four Stroke and Two Stroke Engines –Scavenging Process, Firing Order.
Unit 2	**Combustions in SI and CI Engines** Stages of Combustion, Ignition Systems. Dependence of Ignition Timing on Load and Speed, Detonation and Knocking in SI and CI Engines. Combustion Chambers for SI and CI Engines. Direct and Indirect Injection Combustion Chambers for CI Engines. Importance of Swirl, Squish and Turbulence. Factors Controlling Combustion Chamber Design,
Unit 3	**Fuel injection, Ignition and Engine performance** Fuel injectors, Diesel injection system, MPFI, CRDI, Battery and Magneto ignition system, electronic ignition system, Introduction to carburetors. A: F mixture, Testing of Engine, Determination of BP, IP, performance characteristics, Energy balance

Syllabus

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Unit	Contents
Unit 4	**Engine emission and control** Types of emission: Formation of carbon monoxide, unburnt hydrocarbon, oxides of nitrogen, smoke and particulate matter, methods of controlling emissions, catalytic converters, selective catalytic reduction and particulate traps, methods of measurement, emission norms
Unit 5	**Alternates fuels for IC Engines** Biodiesel, Hydrogen, CNG, LPG etc Its merits and demerits, engine modification. HCCI Engine, Flex Engines, GDI, RCCI, Multi Fuels Engines, Fuel cell

Study Material

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Text Books	1.	Ramalingam. K.K., "Internal Combustion Engine Fundamentals", Scitech Publications, 2002. .
	2.	Ganesan, "Internal Combustion Engines", II Edition, TMH, 2002. .
E-Books	1.	I C Engine and Gas Turbine , Prof Pranb K Mandolaand Prof Vinayak Kulkarni – IIT Guwahati https://archive.nptel.ac.in/courses/112/103/112103262/
	2.	Non-Conventional Energy Resources, SobhNath Singh, Kindle Edition e-Textbook.
Reference Books	1.	Mathur. R.B. and R.P. Sharma, "Internal Combustion Engines", DhanpatRai& Sons 2007. .
	2.	Duffy Smith, "Auto Fuel Systems", The Good Heart Willcox Company, Inc., 1987
	3.	Eric Chowenitz, "Automobile Electronics", SAE Publications, 1995.

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Unit 1

Introduction to Engine

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Engine Classification: Engines can be classified based on the following criteria:

- **Fuel Type:** Petrol engines, Diesel engines, and Gas engines
- **Cylinder Arrangement**: (Vertical engine ,Horizontal engine ,Radial engine V-engine ,Opposed cylinder engine, Opposed piston engine)
- **Number of stroke per cycle:** Four stroke engine Two stroke engine
- **Mixture Formation:** Premixed and Diffusion
- **Type of Ignition** (Spark-Ignition - Compression-Ignition)
- **Cooling Technique** (Air-Cooled - Water-Cooled)
- **Cylinder Filling Method** (Naturally Aspirated - Turbo-Charged - Supercharged)
- **Valve Arrangement**:L-Head, I-Head, F-Head

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Constructional Details and working principle of Spark Ignition (SI)

- **Cylinder block** is made of cast iron because of its good wear resistance and low cost.
- **Cooling water passages** are provided in the block during casting.
- **Piston** is made of aluminum in small engines and cast steel in bigger engines.
- **Combustion chamber**: space between the cylinder head and the piston crown
- **Connecting rod:** piston is connected to the crankshaft through a connecting rod made of forged steel.

The connecting rod-crank assembly converts the reciprocating motion of the piston to rotary motion.

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Constructional Details and working principle of Spark Ignition (SI)

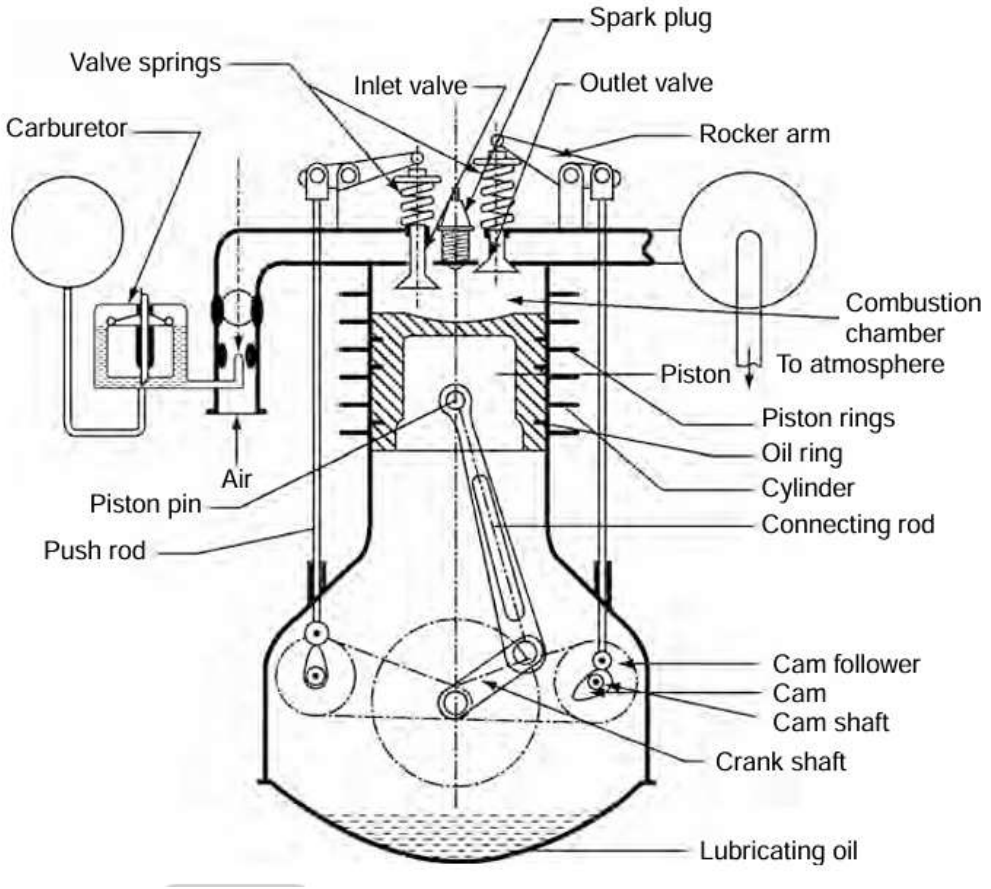
- **Crankshaft** is supported in bearings mounted in the crank case which is sealed at the bottom with a pressed-steel or cast-aluminium oil pan acting as an oil reservoir for the lubrication system.
- **Piston rings** do not permit the high pressure gases to escape through the gap between the cylinder wall and the piston and also scraps the excess oil from the cylinder walls and allows the oil to return to the oil pan.
- **Valves** made of chrome – nickel alloy are usually poppet valves and are operated by a cam.
- **Camshaft** is made of forged steel and is driven by the crankshaft through gears

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Compression Ignition (CI) Engines**and working principle of Spark Ignition (SI)**

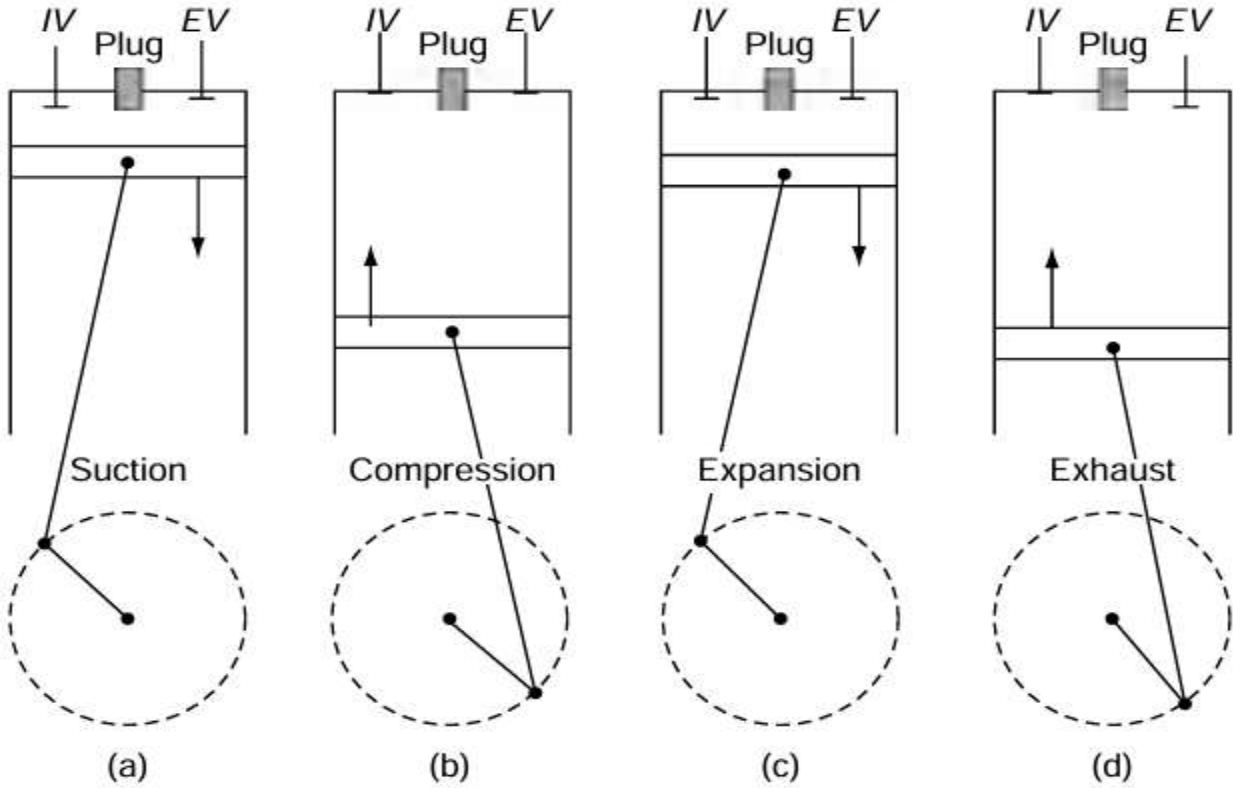


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Working principle of Spark Ignition (SI)



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Working principle of Spark Ignition (SI)

Suction Process :Let us consider that the piston is at the top dead centre (tdc) and the crankshaft is being rotated so that the piston moves downwards (from tdc to bdc) and the inlet valve opens to admit a homogeneous mixture of air and fuel inside the engine cylinder.

Compression Process The fresh charge admitted during the suction process mixes with the residual gases present inside the cylinder and the mixture is compressed to a higher pressure when the piston describes the return stoke, i.e., moves from the bdc to tdc, while the valves, inlet and outlet, are closed.

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Working principle of Spark Ignition (SI)

Ignition and Expansion Process Near the end of the compression stroke, there is an electric discharge across the spark plug, between 10 and 40 crank angle degrees before tdc, and that initiates the combustion process. The fuel burns and the combustion process is completed within a few milliseconds. And liberated heat energy rapidly increases the pressure and temperature of the working fluid present inside the cylinder. The products of combustion exert pressure at the piston crown and the piston is forced to descend downwards, from tdc to bdc, Fig. (c). During this expansion process, both the valves are closed.

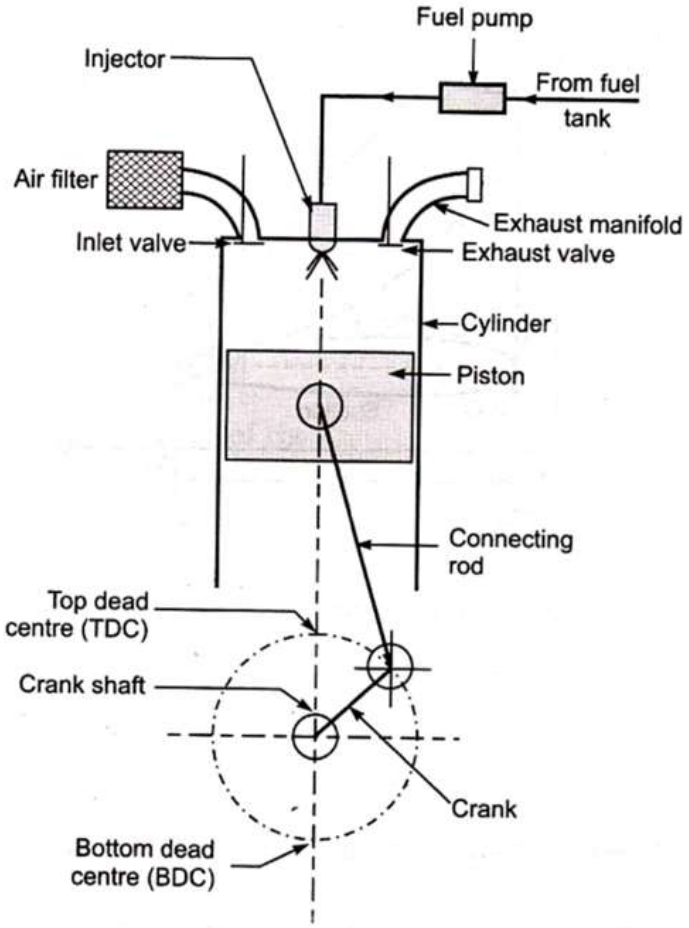
Exhaust Process The exhaust valve opens near the end of the expansion process and the burned gases are forced out of the cylinder by the piston moving from bdc to tdc.

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Constructional Details of Compression Ignition (CI) Engines



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[redacted]rking principle of Compression Ignition (CI) Engines

Suction Process Air alone is admitted inside the cylinder through the inlet valve while the piston moves from tdc to bdc. The inlet valve starts opening at about 30 before tdc so that it is fully open before the piston describes the suction process.

Compression Process The piston compresses the air admitted earlier while moving from bdc to tdc and during this process both the valves should remain closed. The compression ratio varies from 12:1 to 24:1 and the air is compressed to a very high pressure, about 4 MPa, and as such the temperature at the end of the compression stroke is about 800 K

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Working principle of Compression Ignition (CI) Engines

The fuel usually a light fuel oil, is injected directly into the engine cylinder nearly at the end of compression stroke. The injection starts at about 20 deg before tdc and continues during a part of the expansion process.

Combustion and Expansion Process The liquid fuel enters the engine cylinder in the form of a fine spray and after entering the cylinder, it atomises, evaporates and mixes with heated air to form a combustible mixture. Since the temperature of air is much more than the self ignition temperature of the fuel, the fuel autoignites and the flame rapidly spreads through the combustion chamber. The products of combustion push the piston downwards from tdc to bdc, and the expansion stroke completed.

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Working principle of Compression Ignition (CI) Engines

Exhaust Process The exhaust valve starts opening at about 30° before the bdc (before the completion of the expansion process) and a substantial part of the working fluid leaves the cylinder during the expansion process itself. During the exhaust process, the piston moves from the bdc to tdc and the gases are pushed out of the cylinder and the exhaust valve close at about 30 deg after tdc. The sequence of events that take place inside the engine cylinder of a 4-stroke CI engine

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Air Standard Cycles

1. Otto cycle
2. Diesel cycle
3. Dual cycle

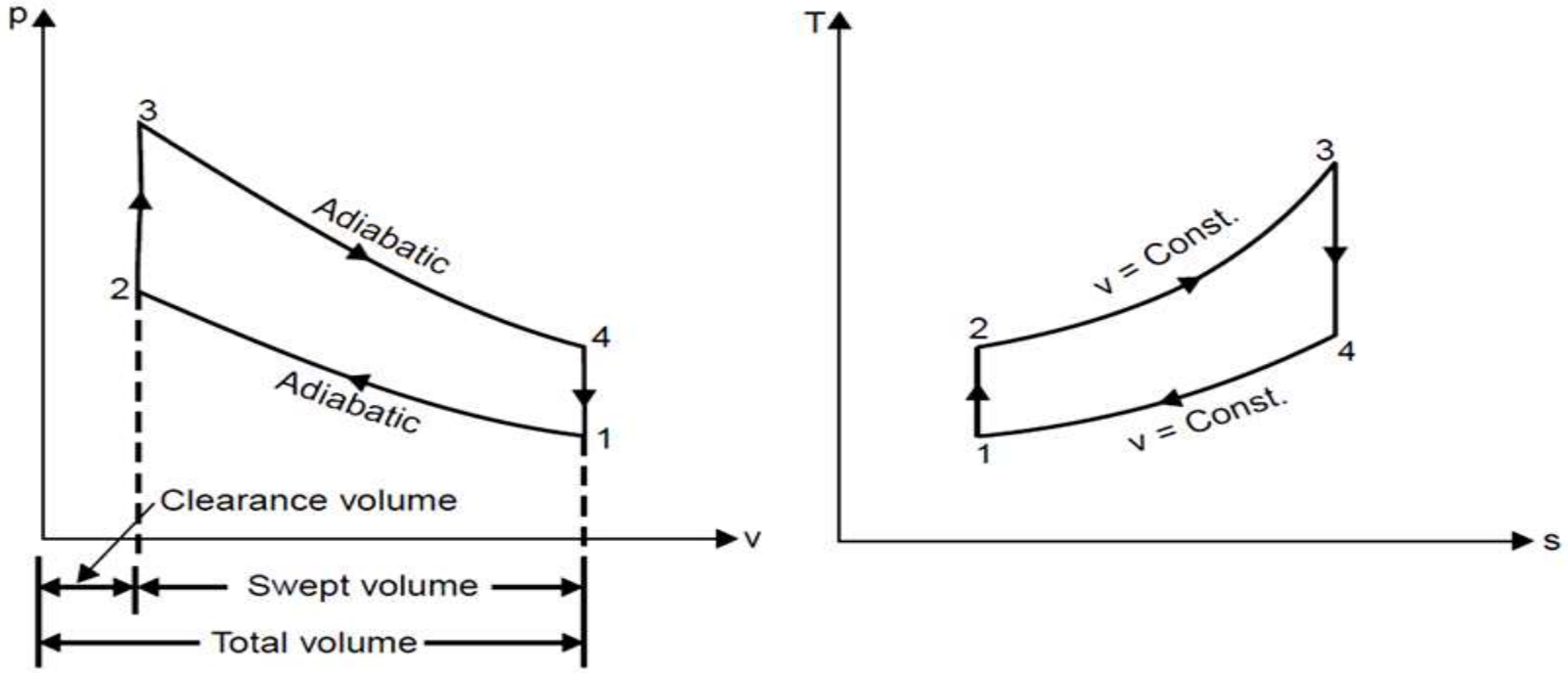
Otto cycle: The thermodynamic cycle is operated with isochoric (constant volume) heat addition and consists of two adiabatic processes and two constant volume changes.

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Air Standard Cycles

Otto cycle: Fig. shows the Otto cycle plotted on P– V and T – S diagram.



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Air Standard Cycles

Otto cycle:

- Adiabatic Compression Process (1 – 2):

At pt. 1 cylinder is full of air with volume V1, pressure P1 and temp. T1. Piston moves from BDC to TDC and an ideal gas (air) is compressed isentropically to state point 2 through compression ratio,

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

- Constant Volume Heat Addition Process (2 – 3):

Heat is added at constant volume from an external heat source. The pressure rises and the ratio

$$r_p \text{ or } \alpha = \frac{p_3}{p_2}$$

is called expansion ratio or pressure.

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Air Standard Cycles

Otto cycle:

- Adiabatic Expansion Process (3 – 4):

The increased high pressure exerts a greater amount of force on the piston and pushes it towards the BDC. Expansion of working fluid takes place isentropically and work done by the system.

The volume ratio $\frac{V_4}{V_3}$ is called isentropic expansion ratio.

- Constant Volume Heat Rejection Process (4 – 1):

Heat is rejected to the external sink at constant volume. This process is so controlled that ultimately the working fluid comes to its initial state 1 and the cycle is repeated.

Many petrol and gas engines work on a cycle which is a slight modification of the Otto cycle.

This cycle is called constant volume cycle because the heat is supplied to air at constant volume.

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Air Standard Cycles

Otto cycle:

- Air standard efficiency of the Otto cycle is

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

Diesel cycle

- Diesel cycle is also known as constant pressure heat addition cycle.

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Air Standard Cycles

Diesel cycle

Diesel cycle is also known as constant pressure heat addition cycle.

- Adiabatic Compression Process (1 – 2): Isentropic (Reversible adiabatic) compression with $r = \frac{V_1}{V_2}$.
- Constant Pressure Heat Addition Process (2 – 3): The heat supply is stopped at point 3 which is called the cut – off point and the volume ratio is called cut off ratio or Isobaric expansion ratio.

$$\rho = \frac{V_3}{V_2}$$

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Air Standard Cycles

Diesel cycle

- Adiabatic Expansion Process (3 – 4)

Isentropic expansion of air :

$$\frac{V_4}{V_3} = \text{isentropic expansion ratio.}$$

- Constant Volume Heat Rejection Process (4 – 1):

In this process heat is rejected at constant volume. − This thermodynamics cycle is called constant pressure cycle because heat is supplied to the air at constant pressure.

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Air Standard Cycles

Diesel cycle

Air Standard Efficiency for Diesel Cycle:

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

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Air Standard Cycles

Dual Cycle

This cycle is also called as the dual cycle, which is shown in Fig. Here the heat addition occurs partly at constant volume and partly at constant pressure. This cycle is a closer approximation to the behavior of the actual Otto and Diesel engines because in the actual engines, the combustion process does not occur exactly at constant volume or at constant pressure but rather as in the dual cycle.

Process 1-2: Reversible adiabatic compression. Process 2-3: Constant volume heat addition. Process 3-4: Constant pressure heat addition. Process 4-5: Reversible adiabatic expansion. Process 5-1: Constant volume heat rejection.

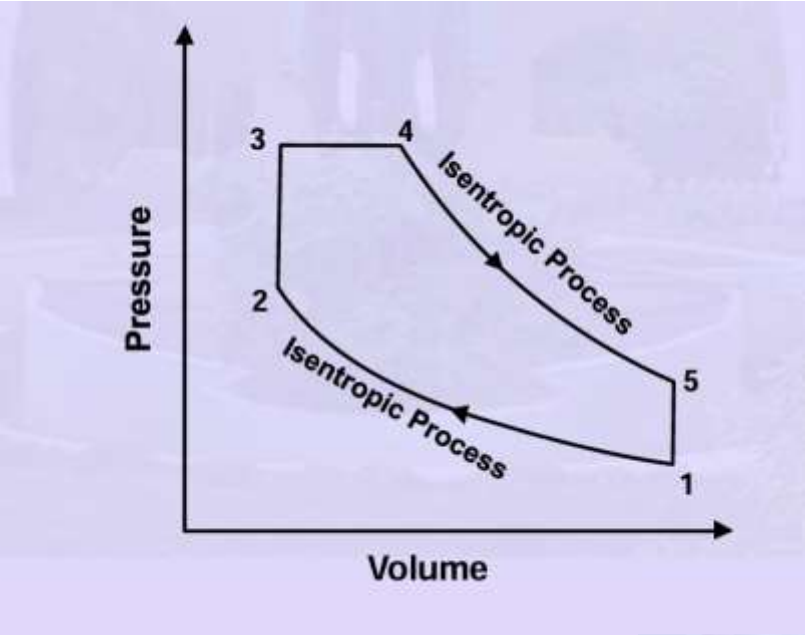
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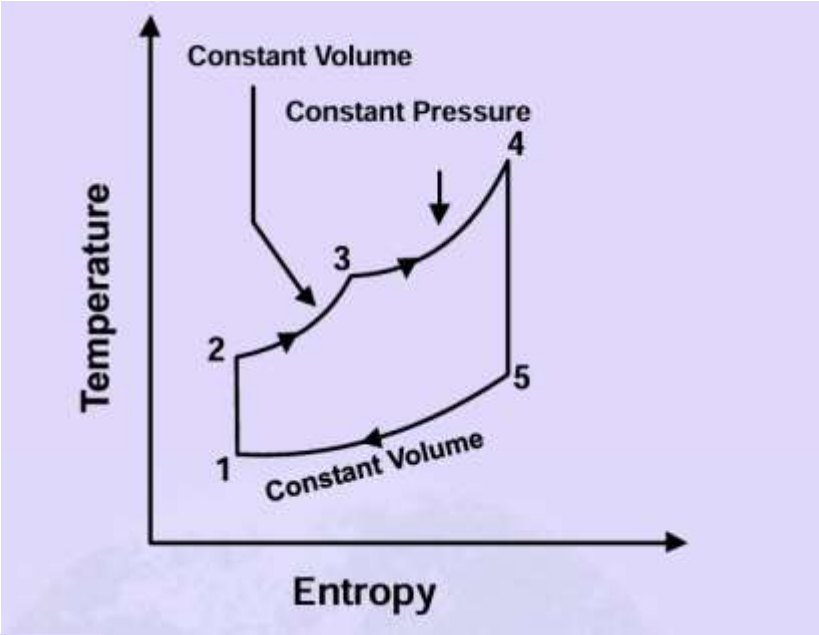
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Air Standard Cycles

Dual Cycle





$$\eta_{th}\ 1 - \frac{1}{r^{\gamma - 1}}\left\{\frac{r_p\ r_c^{\gamma} - 1}{(r_p - 1) + \gamma r_p (r_c - 1)}\right\}$$

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Four Stroke

Four Stroke Cycle Engine:The cycle consists of four stroke of piston completed in two revolution of crankshaft. Each stroke is completed in 180° of crank rotation. The four strokes are:

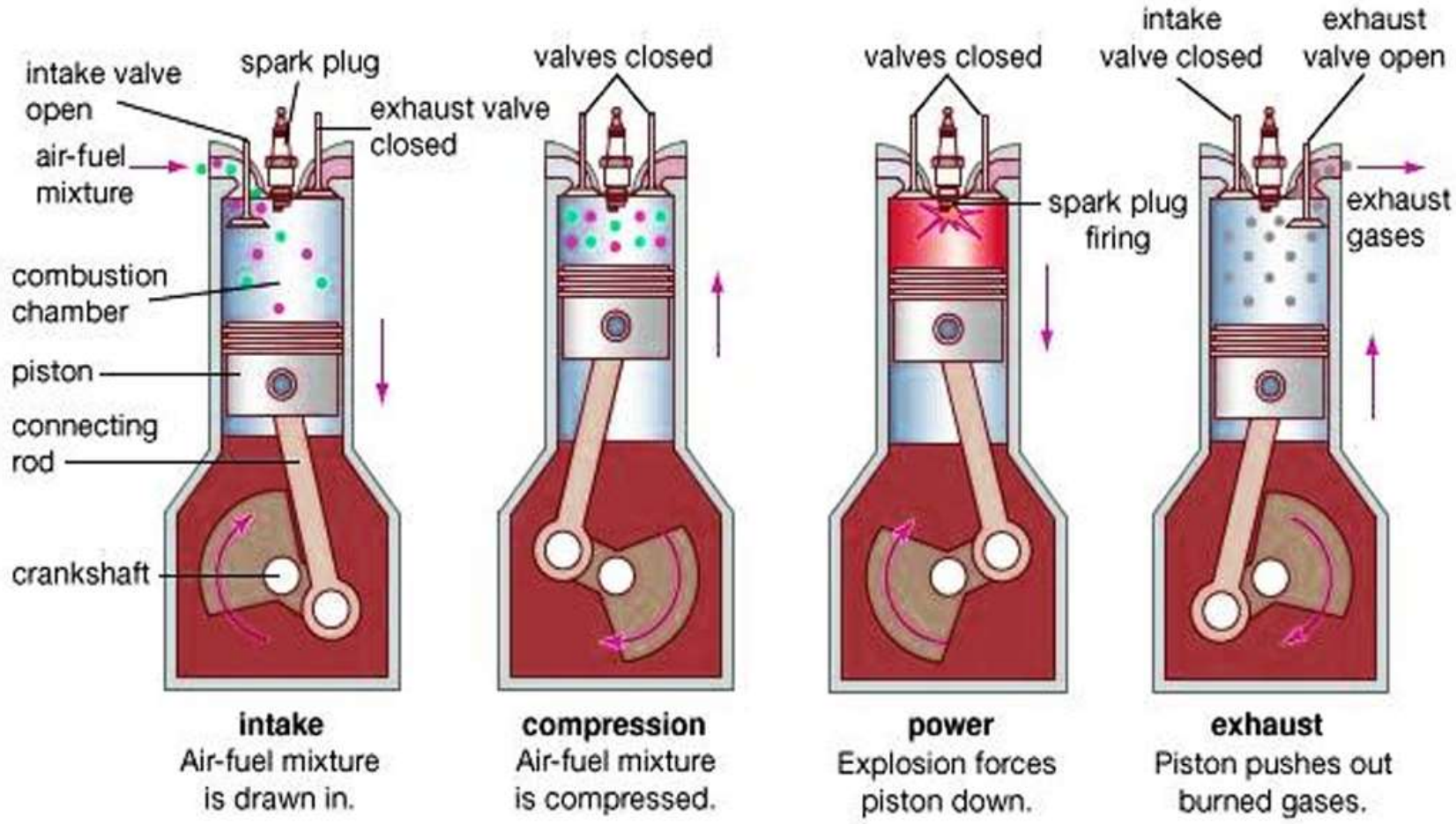
- Suction Stroke
- Compression Stroke
- Expansion or Power Stoke
- Exhaust Stroke

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Four Stroke



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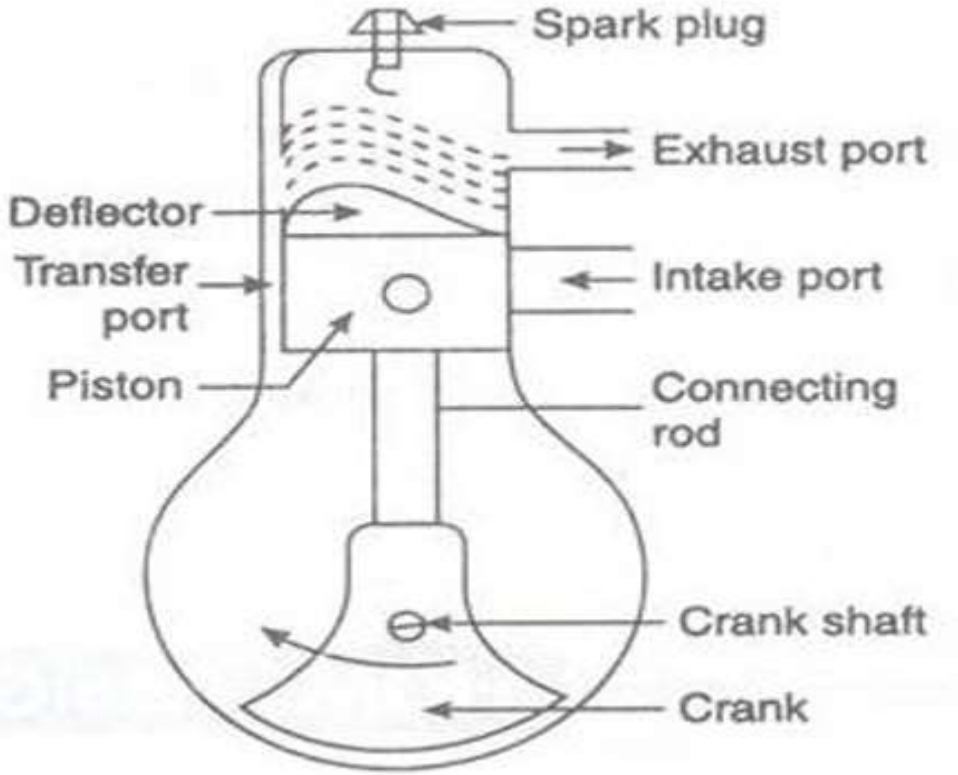
Two Stroke :

- In two stroke engines, the two strokes named as upward and downward, carried out all four operations i.e. suction, compression, expansion and exhaust.
- The two stroke cycle consists of two stroke of piston completed in one revolution of crankshaft. In other words, one working stroke is completed in one revolution of crank shaft.
- Thus, theoretically for same size, two stroke engines should produce double the power as compared to four stroke engines but, it is not possible practically due to number of losses which are difficult to eliminate

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Two Stroke



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Two Stroke

The two stroke engines does not contain valves, but instead inlet and exhaust ports cut in the cylinder wall and there is also transfer port which connects the cylinder with crank case which is made air tight as shown in figure. Piston in two stroke engine is also acting as a valve covering and uncovering the ports at right time.

Upward Stroke

During upward stroke, the piston moves upward from B.D.C. to T.D.C., compressing an air/fuel mixture in the engine cylinder. At the same time at the bottom side of the piston, a partial vacuum is created in the crank case which pulls another fresh charge of air/fuel mixture into the crankcase through uncovering inlet port. The exhaust and transfer ports are uncovered when the piston approaching towards T.D.C. Near the top of the stroke the compressed air/fuel above the piston is ignited by the spark plug and begins to burn.

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Two Stroke

Downward Stroke

During downward stroke, the piston moves upward from T.D.C. to B.D.C. The rapidly burning fuel expands and begins forcing the piston down, rotating the crankshaft thus doing useful work. During this stroke the inlet port is covered by the piston and admitted charge is compressed in the crank case. As it continues travel downward it uncovers the exhaust port then transfer port. Exhaust gas begins to rush out of the cylinder. As soon as transfer port opens, the fresh air/fuel charge in the crankcase is forced into the cylinder and strikes to the deflector on piston crown rises the top of cylinder and pushes the remaining exhaust gases out. The piston is at B.D.C. position now and cylinder is completely filled with fresh air fuel mixture although it is somewhat diluted with exhaust gases.

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Scavenging Process

- Clearing exhaust gas from the cylinder and replenishing the cylinder with fresh air.
- **Cross Flow Scavenging** is the gas exchange process in which the charge air passes is directed upwards, passing under the cylinder cover and down the opposite side, expelling exhaust gas through exhaust ports on that side.
- This system is obsolete now. - It is the simplest system - Lower efficiency - Rare in diesel engine, however it is used in petrol engine.

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Scavenging Process

- **Loop Scavenging** is the gas exchange process in which he charge air passes over the piston crown and rises to form a loop within the cylinder, expelling exhaust gases through exhaust ports cut in the same side of the liner above the scavenge ports.
- The inlet air ports are angled to give rotary swirling effect to the incoming air.
- It also required long piston skirt to prevent scavenging air leak into exhaust while the piston is at top of it's stroke.
- Simplicity, Reliability and cylinder cover is simplified. - Temperature gradient exhaust to scavenge ports is high
- Exhaust back pressure higher with deposits
- Possibility of intermixing air and gases.
- Piston and liner distortion and uneven piston ring wear due to ports.
- Scavenge efficiency is lower than uniflow scavenge efficiency.

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Scavenging Process

Uniflow scavenging is the gas exchange process in which the charge air passes straight up through the length of the cylinder, forcing the exhaust gas through exhaust valve at the top of the cylinder.

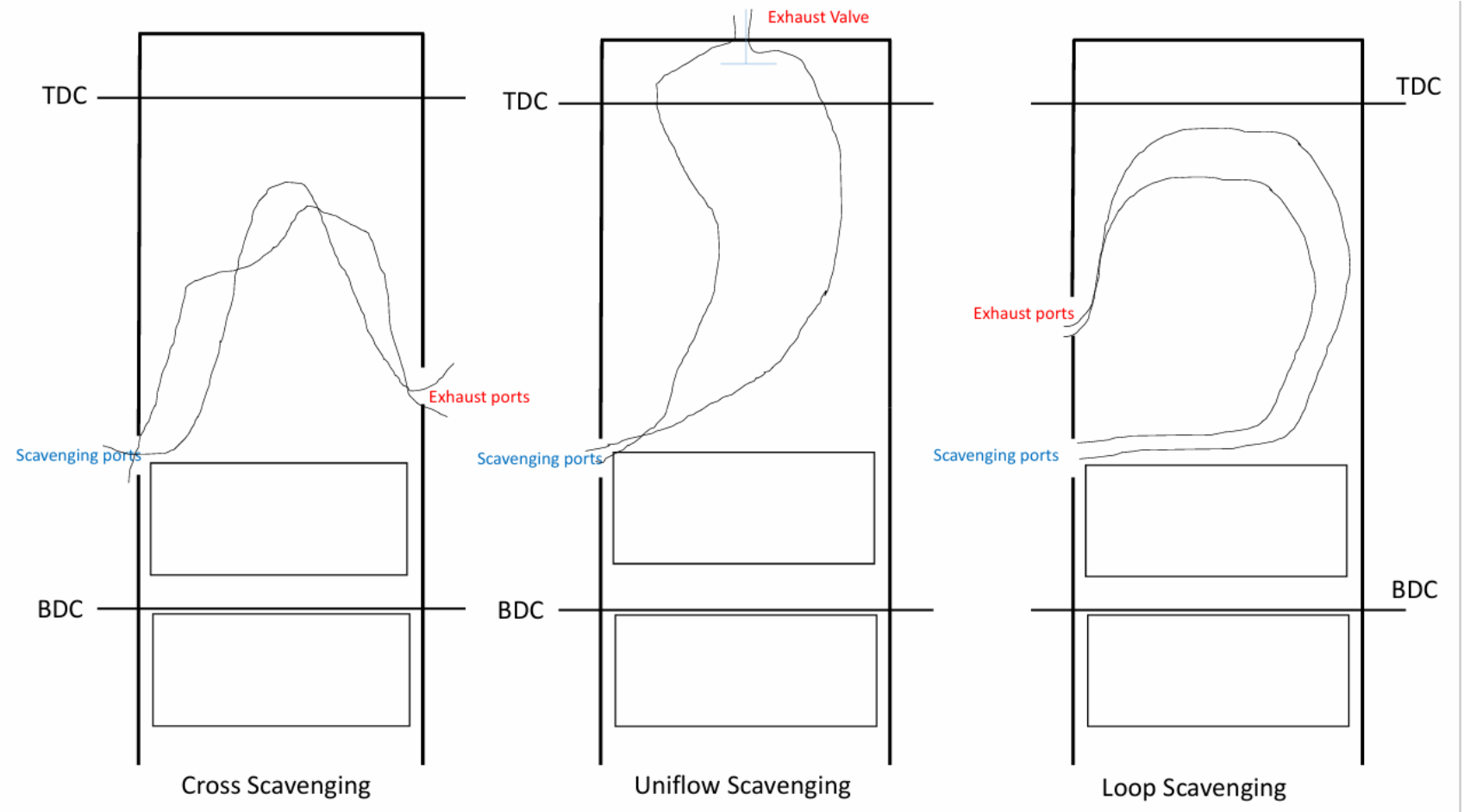
- It is used extremely wide range of engines from small to large engine (15000 kW).
- Highest scavenge efficiency.
- Drop in scavenge efficiency lowest with high scavenge pressure
- Most suitable for pressure charging
- Greater area for air and gas flow
- Possibility of short circuiting and mixing less Disadvantages
- Complicated cylinder head and increased maintena

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Scavenging Process



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Firing Order

- The firing order is the sequence of power delivery of each cylinder in a multi-cylinder reciprocating engine.
- This is achieved by sparking of the spark plugs in a gasoline engine in the correct order, or by the sequence of fuel injection in a Diesel engine.
- When designing an engine, choosing an appropriate firing order is critical to minimizing vibration and achieving smooth running, for long engine fatigue life and user comfort, and heavily influences crankshaft design

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Unit 2

Combustions in SI and CI Engines

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Stages of Combustion in SI Engine

The actual p- Θ diagram with combustion is very complicated but as per this figure it is divided into three stages namely;

Stage I - Ignition lag:

- Ignition lag is the duration between spark (point A) and starting of combustion (point B).
- At point B, first rise of pressure detected and the actual curve differs from motoring curve. So time interval between spark (point A) and first pressure rise (point B) is known Ignition lag
- Ignition lag is also known as preparation phase during which spark, chemical process takes place, and flame generates. In SI engine combustion ignition lag is very important and it should be as small as possible for getting more power.

Combustions in SI and CI Engines

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Stages of Combustion in SI Engine

Stage II - Flame propagation:

- The time duration between point B (combustion starts) and point C (Peak pressure) is known as flame propagation.
- The most of the heat is generated during this phase. Normally spark will occur (Point A) approximately 30° to 35° before TDC, so that peak pressure (Point C) is obtained 5° to 10° after TDC at cruising speed.
- As speed vary this spark timing should vary forgetting peak pressure at 5° to 10° after TDC.

Combustions in SI and CI Engines

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Stages of Combustion in SI Engine

Stage III - After burning:

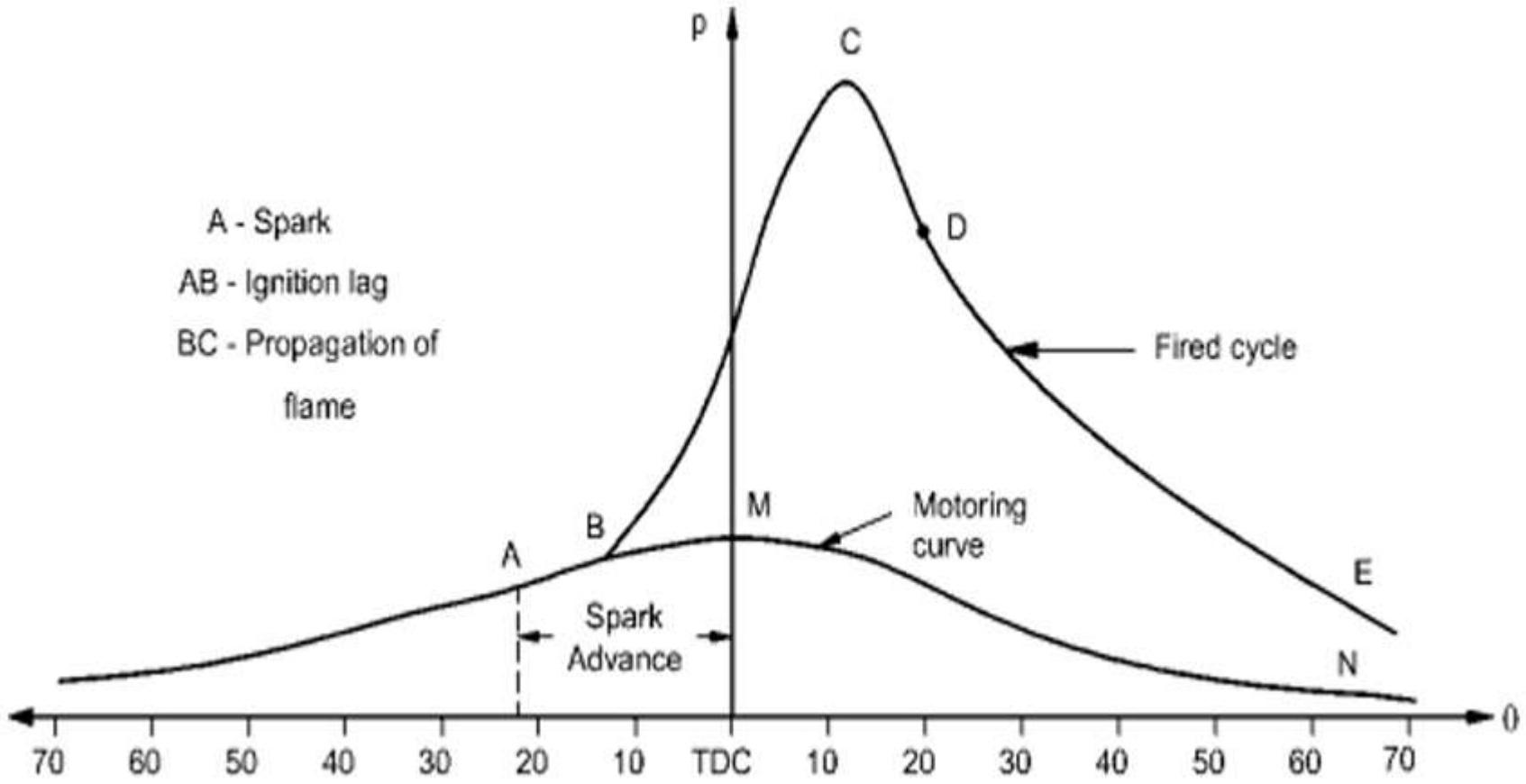
- Theoretically we can say that combustion should be completed at point C i.e. at maximum pressure in Fig.
- But actually combustion will continue after point C i.e. during expansion stroke which is known as after burning.
- It may be due to type of fuel, rich mixture etc. About 10% of heat may be liberated during this stage.

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Stages of Combustion in SI Engine



Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

The fuel is injected by a fuel pump into the combustion chamber by one or more jets under very high pressures of about 120-210 bar pressures at about (20deg.– 35deg.) before TDC. The point A represents the time at which the fuel injection starts on (p -Θ) diagram shown in Fig. Combustion takes place in four stages which are as follows :

First stage (Ignition delay period):

- The fuel leaves the nozzles initially in the form of a jet, and later on, it disintegrates into a core of fuel surrounded by a spray envelope of air and fuel particles due to atomization, vaporization and mixing with hot air.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

- During vaporization process of fuel it receives its latent heat from surrounding air and this causes a slight drop in pressure in the cylinder as shown by curve AB.
- As soon as the vaporization is over, the preflame reactions of the mixture start. During such chemical reactions the energy is released at slow rate and the pressure starts building up.
- Therefore, the preflame reactions first start slowly and then accelerates until the ignition of fuel takes place. It corresponds to point C on diagram.
- The time interval between the start of fuel injection and commencement of combustion is called the delay period.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

The delay period can be divided into two parts as follows :

Physical delay:

- This represents the time interval from the time of injection of fuel to its attainment of self-ignition temperature during which the fuel is atomized, vaporized and mixed with air.

Chemical delay:

- After physical delay period is over, the time interval up to the time the fuel auto-ignites and flame appears is called chemical delay. During this period pre flame reactions take place. This period corresponds to ignition lag of S.I. engines.
- In practice, it is very difficult to separate exactly these two delay periods since the processes involved are very complex.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

Second stage (Period of uncontrolled combustion):

- Once the delay period is over the mixture of fuel and air will auto-ignite since it is above the self-ignition temperature.
- The flame appears at one or more locations where concentration of fuel and air mixture is optimum. This is due to the fact that the mixture present in the combustion chamber at the time of ignition is extremely heterogeneous unlike the homogeneous mixture of S.I. engines.
- Once the flame appears the mixture in other regions will either be burnt by propagating flames or it will auto-ignite because of the heat transfer from the burnt mixture and high temperatures existing in the combustion chamber.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

- The fuel which is accumulated during the delay period is now ready for combustion and it would burn at an extremely rapid rate causing a steep rise in cylinder pressure and temperature.
- The rate of pressure rise depends upon the fuel injected and accumulated, which is directly proportional to the time of injection and the engine speed.
- Higher the delay period, higher would be the rate of pressure rise. During this period it is difficult to control the amount of fuel burning, for this reason, this period of rapid combustion is called the period of uncontrolled combustion as represented by curve CD in Fig.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

Third stage (Period of controlled combustion):

- Once the fuel accumulated during the delay period is burnt in the period of uncontrolled combustion, the temperature and pressures in the cylinder will be so high that the further quantity of fuel injected will burn as soon as it leaves the nozzle provided sufficient oxygen is present in the cylinder.
- Therefore the rate of pressure rise can now be controlled by controlling the rate of fuel injection. This period of combustion is known as period of controlled combustion represented by curve DE.

Combustions in SI and CI Engines

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Stages of Combustion in CI Engine

Fourth state (After burning):

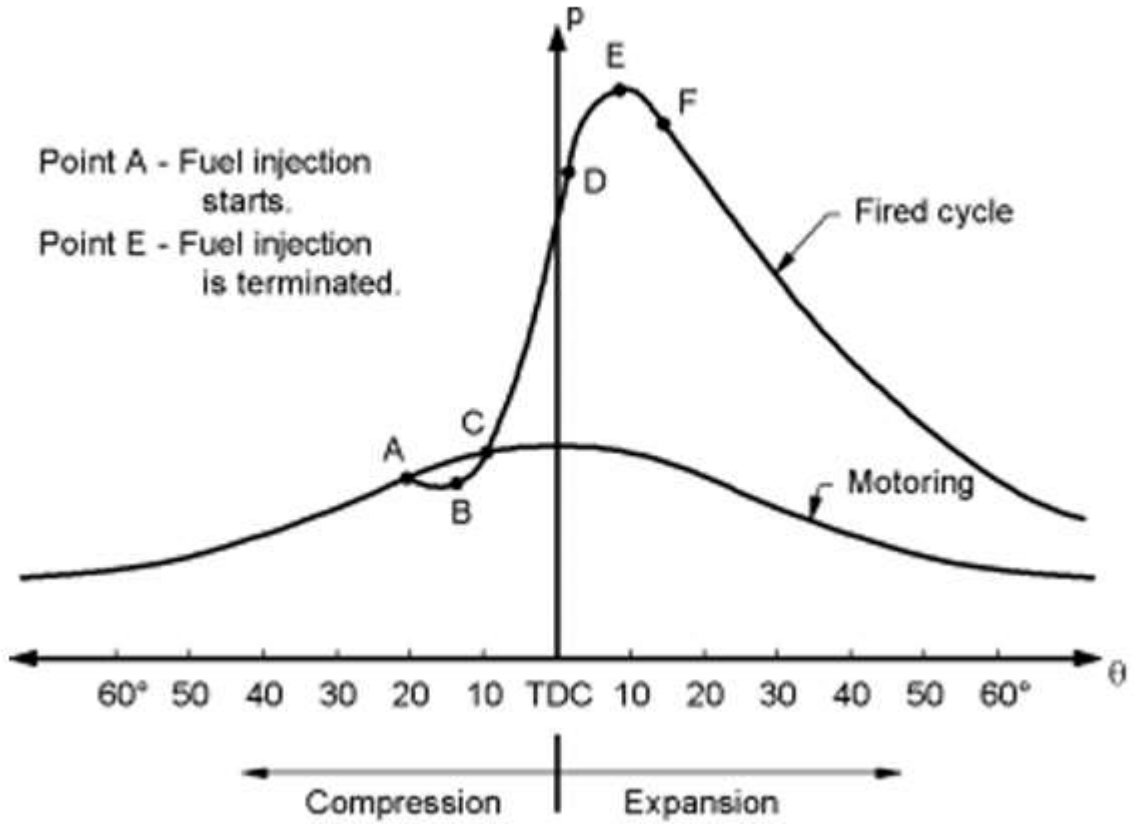
- Theoretically the combustion is completed at the point the maximum pressure is attained during the cycle corresponding to point E few degree after TDC.
- However, the burning of fuel continues during its expansion stroke due to reassociation of dissociated gases and any unburned fuel due to heterogeneous condition of mixture. This phase of combustion is called after burning.

Combustions in SI and CI Engines

L-12

Stages of Combustion in CI Engine

.



Combustions in SI and CI Engines

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L-13

Ignition Systems.

- The ignition system is a system used to generate a very high voltage from the car battery and to send it to each sparkplug in turn thereby igniting the fuel-air mixture in the combustion chamber of the engine.

Types of Ignition System:

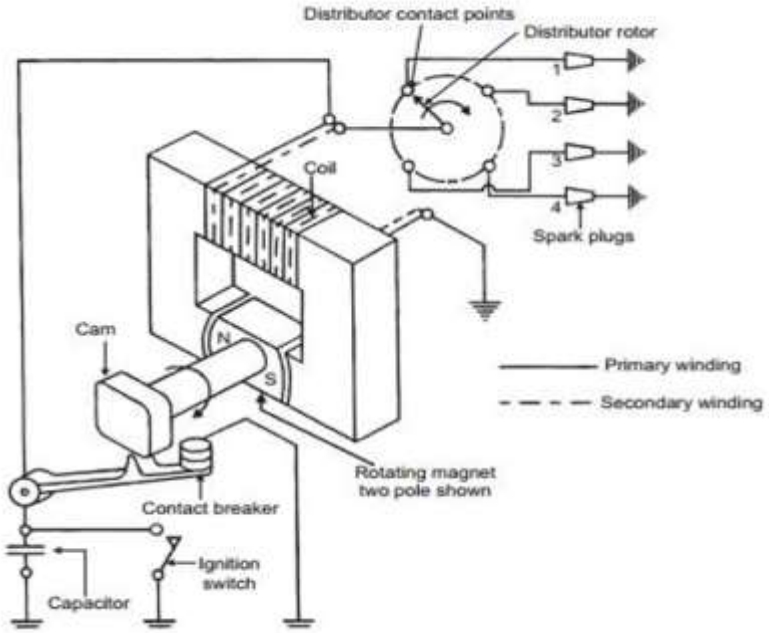
- Magneto ignition systems
- Battery coil ignition systems
- Electronic ignition system

Combustions in SI and CI Engines

L-13

Ignition Systems.

Magneto ignition systems: The main components of an ignition coil are Distributor, Condenser, Contact Breaker (CB) points, Ignition Coil.



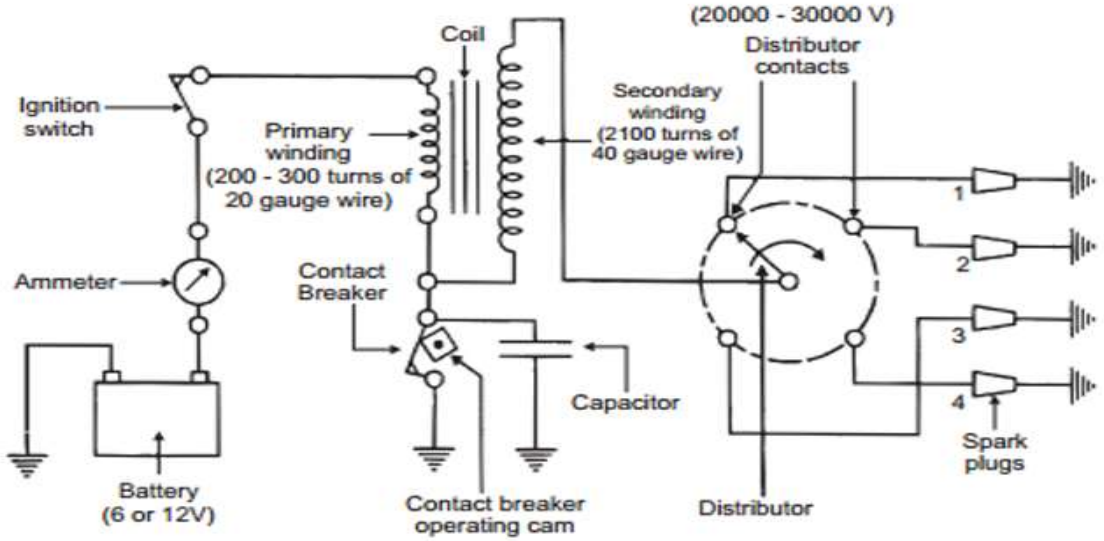
Combustions in SI and CI Engines

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Ignition Systems.

Battery coil ignition systems : It mainly consists of a 6 or 12 volt battery, ammeter, ignition switch, auto-transformer (step up transformer), contact breaker, capacitor, distributor rotor, distributor contact points, spark plugs, etc.



Combustions in SI and CI Engines

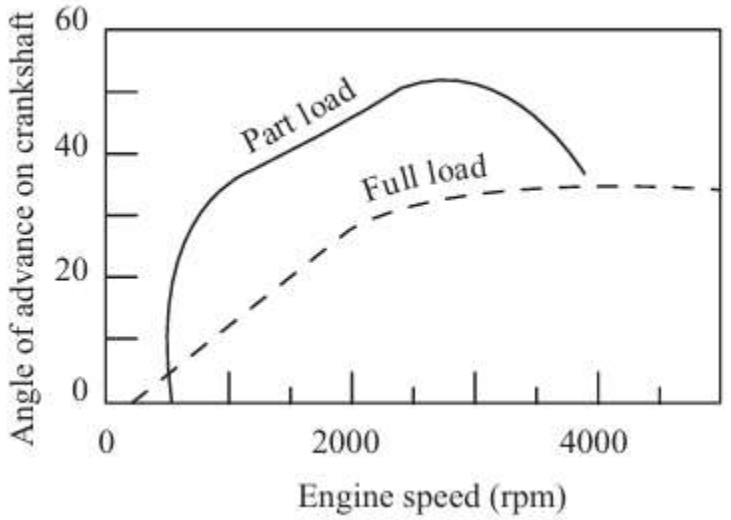
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L-14

Dependence of Ignition Timing on Load and Speed

Engine Speed:

- engine speed is increased it will be necessary to advance the ignition progressively



Combustions in SI and CI Engines

L-14

Dependence of Ignition Timing on Load and Speed

Engine Load :

- Part load operation of a spark ignition engine is affected by throttling the incoming charge. Due to throttling a smaller amount of charge enters the cylinder and the dilution due to residual gases is also greater. This results in the combustion process being slower.

Combustions in SI and CI Engines

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Detonation and Knocking in SI and CI Engines.

Knock in C.I. Engines

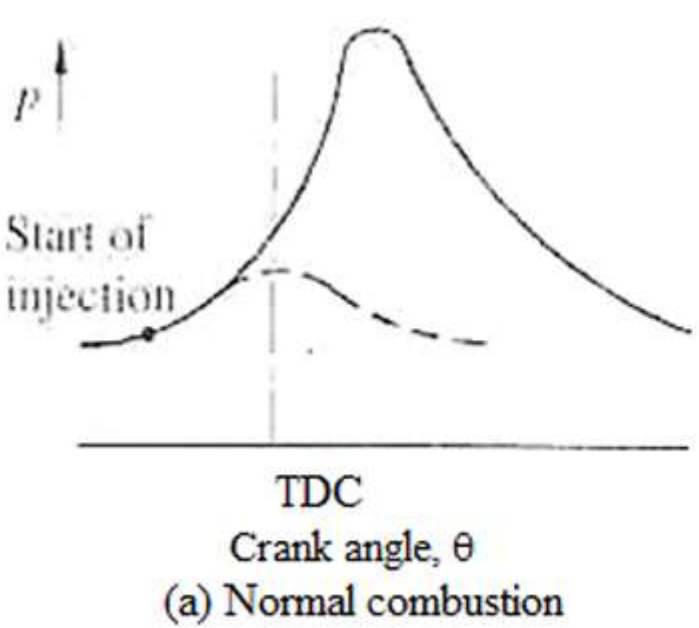
- In C.I engine as delay period increases, the amount of fuel injected and accumulated in combustion chamber increases. A very high temperature and pressure is generated by combustion of this large amount of fuel is known as knocking or detonation in C.I engine.
- "Accumulation of fuel during large delay period creates very high pressure, it is known as knocking in C.I. engine."
- This high rate of pressure rise creates pulsating combustion which produces heavy noise.
- In C.I. engine knocking occurs during initial phase of combustion i.e. as delay period is completed and uncontrolled combustion starts.

Combustions in SI and CI Engines

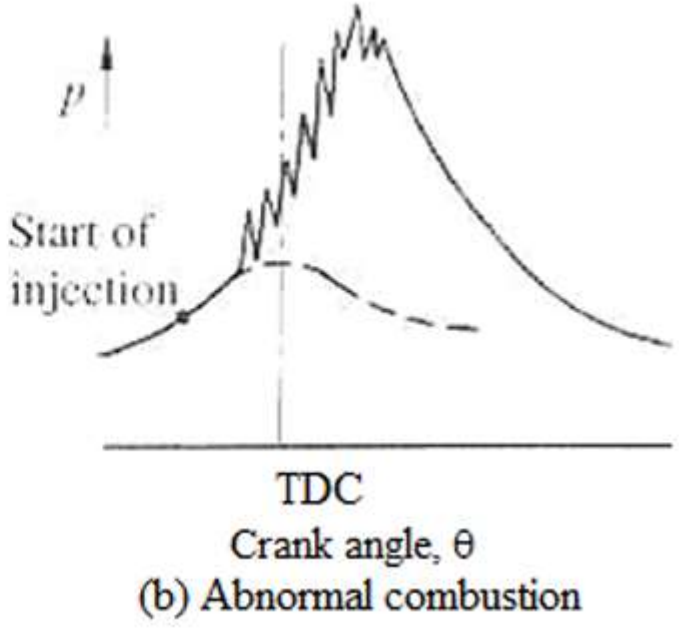
L-15

Detonation and Knocking in SI and CI Engines.

Knock in C.I. Engines



(a) Normal combustion



(b) Abnormal combustion

Combustions in SI and CI Engines

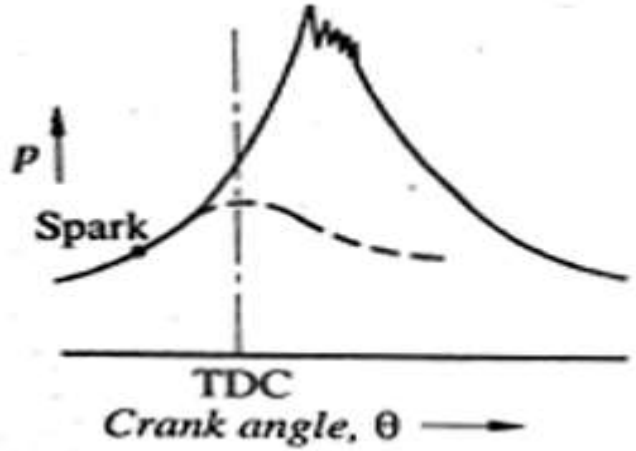
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L-15

Detonation and Knocking in SI and CI Engines.

Knock in S.I. Engines

- In S.I. engine knocking takes place at the end of combustion process .
- In S.I. engine knocking is due to end charge auto-ignition before reaching the flame.
- In S.I. engine pressure rise is very high during knocking due to homogeneous mixture



Combustions in SI and CI Engines

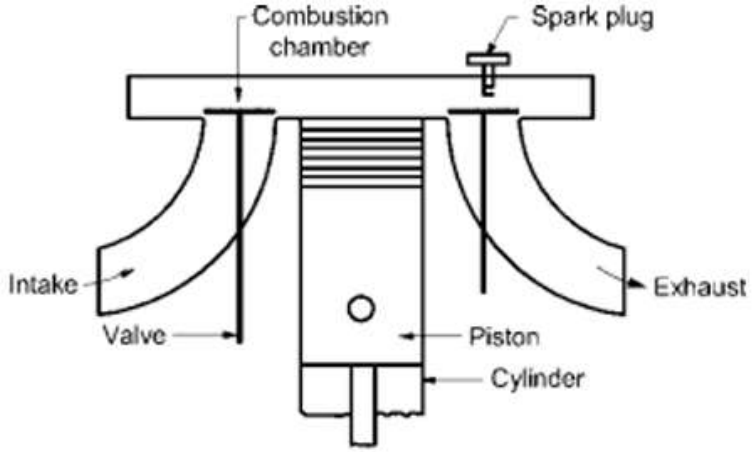
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L-16

Combustion Chambers for SI and CI Engines.

Types of S.I. combustion chamber

T-Head Combustion Chamber This type of combustion chamber is shown in Fig. It has the following disadvantages : 1. It needs two cam shafts to operate each valve separately. 2. Long flame travel, therefore, it has more tendency to detonate. Compression ratios were limited to 5 : 1. 3. Has high surface-volume ratio.



Combustions in SI and CI Engines

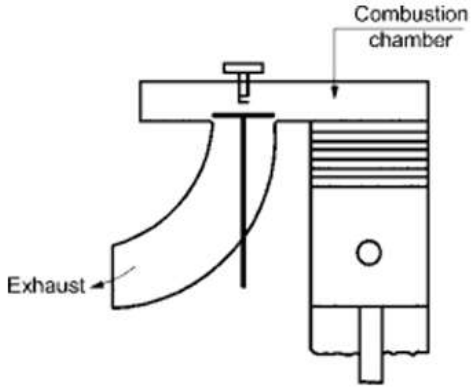
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Combustion Chambers for SI and CI Engines.

Types of S.I. combustion chamber

L-Head or Side Valve Combustion Chamber: The top surface of the combustion chamber is in the form of a flat slab. Its intake valve and exhaust valve are kept side by side with spark plug location above the valves. Length of the combustion chamber covers the entire piston and valve assembly.



Advantages of L-head combustion chamber :

1. Easy to cast.
2. Easy to carry out maintenance.
3. Easy to lubricate the valve mechanism.
4. Cylinder head can easily be removed, therefore, decarbonizing can be carried out without disturbing the valve gear mechanism.

Combustions in SI and CI Engines

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Combustion Chambers for SI and CI Engines.

Types of S.I. combustion chamber

L-Head or Side Valve Combustion Chamber

Disadvantages of L-head combustion chamber :

1. There is a loss of velocity of intake air since it has to take two right angle turns before reaching the cylinder. It results into poor turbulence.

2. Distance to be travelled by flame is more and it is super imposed by poor turbulence, therefore, tendency to detonation is more. Compression ratio is limited to 4 : 1.

3. Mixing of air-fuel is unsatisfactory.

4. It has low power and low thermal efficiency.

Combustions in SI and CI Engines

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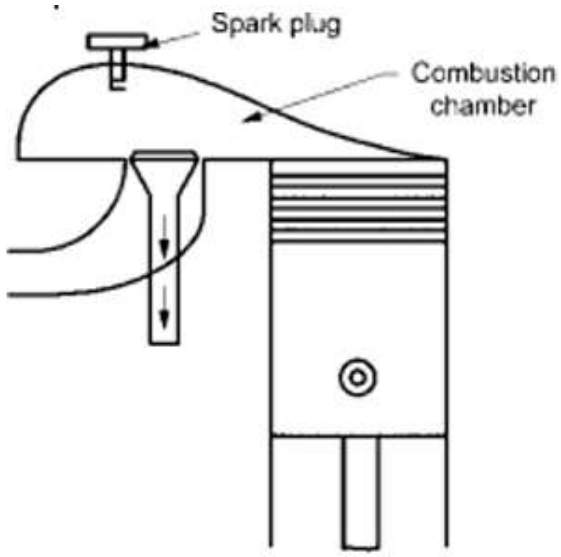
L-16

Combustion Chambers for SI and CI Engines.

Types of S.I. combustion chamber

Recardo Turbulent Combustion Chamber

- The Recardo combustion chamber overcomes the disadvantages experienced in the L head combustion chamber.
- Recardo combustion chamber provid



Combustions in SI and CI Engines

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L-17

Combustion Chambers for SI and CI Engines.

Types of C.I. combustion chamber

- There are four design variants available in Direct Injection type combustion chambers. those are
- Shallow depth chamber
- Hemispherical chamber
- cylindrical chamber
- Toroidal chamber

Combustions in SI and CI Engines

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L-17

Combustion Chambers for SI and CI Engines.

Types of C.I. combustion chamber

- **Shallow depth combustion** chambers are mostly used in the heavy engines running with the low speeds. As you can see the shallow depth chamber diagram, the depth of the cavity provided in the piston is quite small and the diameter is large. Due to the large diameter, there will be almost negligible squish.
- Hemispherical chamber, the depth to the diameter ratio can be varied. so that the squish can be controlled to attain better performance.
- Cylindrical :The shape of the combustion chamber is truncated cone with the base angle of 30°. The Squish can be varied by varying the depth. The swirl can be produced by masking the valve for nearly 180°of the circumference. Squash also can be controlled by varying the depth

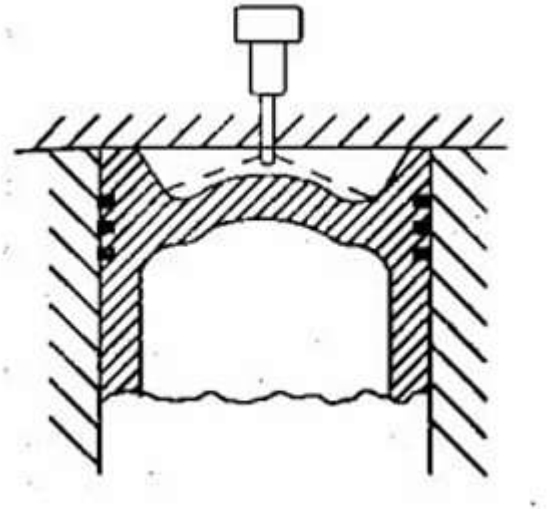
Combustions in SI and CI Engines

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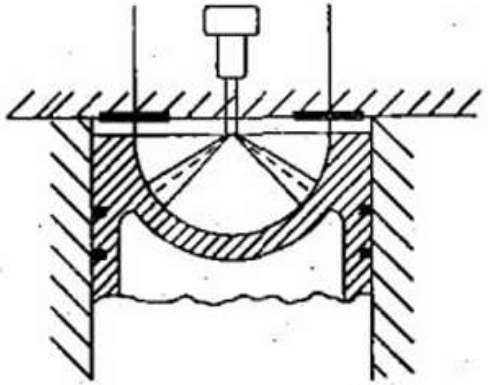
L-17 Combustion Chambers for SI and CI Engines.

Types of C.I. combustion chamber

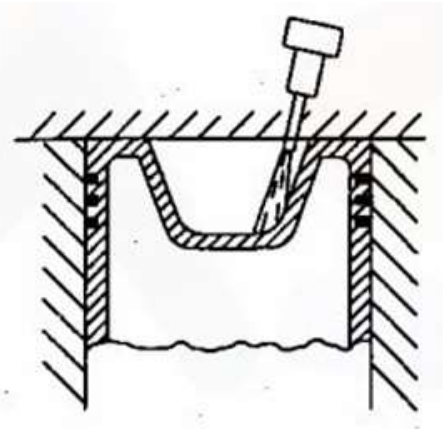
Toroidal chamber design is mainly focused to provide the powerful Squish along with the air moment. As the more Squish, the mask needed on the inlet valve is small and there is better utilization of oxygen.



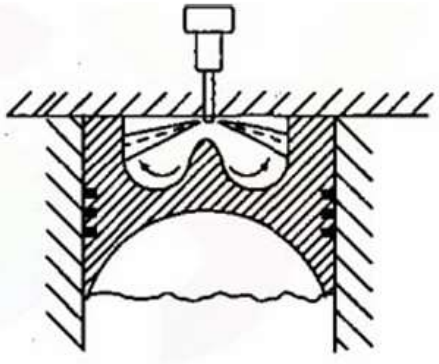
1. Shallow depth chamber



2. Hemispherical chamber



3. Cylindrical Chamber



4. Toroidal Chamber

Combustions in SI and CI Engines

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L-18 . **Importance of Swirl, Squish and Turbulence**

Turbulence

It is essential to have well organised movement of air within the combustion chamber for –

- speedy evaporation of fuel
- to enhance air fuel mixing
- to increase combustion speed and
- to increase efficiency. Due to high velocities involved the flow of air within the combustion chamber is turbulent. Due to turbulence the transfer rates like vaporisation of fuel, heat transfer rates, mixing and combustion rates are greatly increased.

Combustions in SI and CI Engines

L-18

. Importance of Swirl, Squish and Turbulence

Turbulence

- The main aim of the CI combustion chamber design is to ensure proper mixing of fuel with the air in a very short time. To achieve this well organised movement of air is essential. Turbulence in the CI engines is quite systematic and built into the design. It would be desirable to understand various types of movements of the air within the combustion chamber.
- Turbulence is quite high during suction and recedes towards BDC.
- Again during compression the turbulence increases as swirl, squish and tumble.

Combustions in SI and CI Engines

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L-18

. Importance of Swirl, Squish and Turbulence

- **Swirl:**The rotational motion of air within the cylinder is called swirl. The swirl is achieved by a variety of methods like shaping the intake manifold, valve, valve port and at times by suitably contouring the piston. Swirl enhances mixing and makes the flue air mixtures homogeneous. Swirl is the main mechanism to spread the flame within the combustion chamber.
- The swirl ratio used to indicate the extent of rotational motion within the combustion chamber. If the ratio of average angular speed to the engine RPM.

Combustions in SI and CI Engines

L-18 . **Importance of Swirl, Squish and Turbulence**

Following are the main types of swirls:

- **Induction Swirl:**

In this air flow is directed in a particular path while entering the cylinder. This method is generally employed for open combustion chamber.

- **Compression Swirl:**

Here the swirl is produced during the compression stroke air is forced through a passage into swirl chamber made separately during the compression stroke

- **Combustion Induced Swirl:**

This swirl is produced by using the phenomenon of high initial pressure rise due to partial combustion.

Combustions in SI and CI Engines

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L-18 . **Importance of Swirl, Squish and Turbulence**

Squish:

- Radial inward movement of air while the piston reaches the TDC is called Squish. “Squish” can be defined as radically inward flow of air towards the combustion recess by squeezing it out from between the piston and cylinder head during the end of compression stroke.
- This movement of air is due to the fact that most of the modern chambers have clearance volume in the central portional only. While the piston goes moves the TDC the air from the outer edges where there remains no space rushes towards the central portional giving rise to inwards radial motion called squish.

Combustions in SI and CI Engines

L-18

. Importance of Swirl, Squish and Turbulence

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Combustions in SI and CI Engines

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L-19

. Factors Controlling Combustion Chamber Design

Design of combustion chamber for S.I engine is very important for following reasons:

- To achieve high power output.
- To achieve high thermal efficiency.
- Smooth running of engine.
- To avoid knocking or detonation.
- Long life of engine.
- Minimum maintenance of engine.

Combustions in SI and CI Engines

L-19

Factors Controlling Combustion Chamber Design

A combustion chamber needs to be designed to meet the general objectives of developing high power output and high thermal efficiency with smooth running of engine and minimum octane number requirement of fuel. In order to achieve these objectives, following factors are to be kept in mind while designing the combustion chambers of S.I. engines.

- The length of flame travel from the spark plug to the farthest point should be kept minimum to avoid detonation problem. It involves the problem of location of spark plug and shape of combustion chamber. Usually the spark plugs are located at the central location or in some cases dual spark plugs are used. Also, the shape of combustion chambers should be as far as possible spherical to reduce the length of flame travel.
- To achieve high speed of flame propagation, an adequate amount of turbulence also ensures more homogeneous mixture by scouring away the layer of stagnant gas clinging to the chamber walls. However, excessive turbulence should be avoided since it increases the heat transfer losses to cylinder walls and affects the thermal efficiency of the engine.

Combustions in SI and CI Engines

L-19

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. Factors Controlling Combustion Chamber Design

- It should have small surface to volume ratio to minimise heat losses. A hemispherical shape provides minimum surface to volume ratio.
- It should provide large area to the inlet and exhaust valves with ample clearance around the valve head. It reduces the pressure drop across the valves, therefore, improves the volumetric efficiency. Use of sleeve valves are said to have low tendency to detonate compared to poppet valves due to absence of any high temperature area.
- Exhaust valves should not be located near the end gas location of combustion chamber to reduce the possibility of detonation since these valves are hottest spot in the combustion chamber.

Combustions in SI and CI Engines

L-19

. Factors Controlling Combustion Chamber Design

- The combustion chambers should be so designed that it can burn largest mass of the charge as soon as the ignition occurs with progressive reduction in the mass of charge burned towards the end of combustion. Exhaust valve head is the hottest region of combustion chamber. It should be cooled by water jacket or by other means to reduce the possibility of detonation.
- Octane number requirement of fuel increases with bore at the same piston speed when other factor remaining the same. Combustion time and cylinder inner surface temperature also increase with bore. For this reason the S.I. engine cylinder diameters are usually limited to 100 mm.
- Thickness of cylinder walls should be uniform to avoid non-uniform expansion.

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Unit 3

Fuel injection, Ignition and Engine performan

L-20

Fuel injectors:

- It is the component, which delivers finely atomised fuel under high pressure to the combustion chamber of the engine.
- Modern tractor engines use fuel injectors, which have multiple holes.
- Main parts of injector are: nozzle body and needle valve.
- The nozzle body and needle valve are fabricated from alloy steel. The needle valve is pressed against a conical seat in the nozzle body by a spring. The injection pressure is adjusted by adjusting the screw

Fuel injection, Ignition and Engine performance

L-20

Fuel injectors:

The main functions of fuel injection system are:

(i) To measure the correct amount of fuel required by engine speed and load,

(ii) To maintain correct timing for beginning and end of injection, (i

(iii) To inject the fuel into the combustion space against high compression pressure.

(iv) To atomize the fuel for quick ignition.

Fuel injection, Ignition and Engine performance

L-20

Diesel injection system:

Process of fuel injection in diesel engine is of two types:

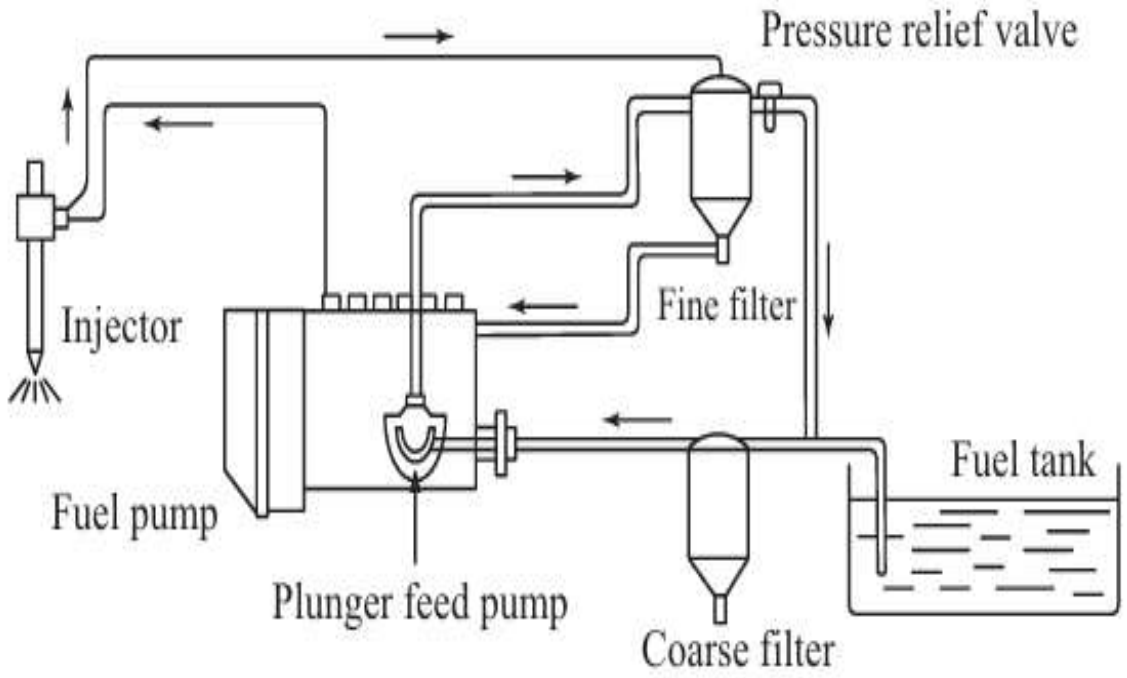
(i) Air injection (ii) Solid injection.

- Air injection: In this process, the engine uses compressed air to force the fuel into the cylinder. It is a bulky system and hence it is not considered very suitable for vehicles and tractors. It is mostly used on heavy-duty stationary engines.
- Solid injection: A high-pressure pump is used for forcing the fuel into the combustion chamber.

L-20

Fuel injection, Ignition and Engine performance

Diesel injection system: A typical arrangement of various components for the solid injection system used in a CI engine is shown in fig



Fuel injection, Ignition and Engine performance

L-20

Diesel injection system:

- Fuel from the fuel tank first enters the coarse filter from which is drawn into the plunger feed pump where the pressure is raised very slightly.
- Then the fuel enters the fine filter where all the dust and dirt particles are removed.
- From the fine filter the fuel enters the fuel pump where it is pressurized to about 200 bar and injected into the engine cylinder by means of the injector.
- Any spill over in the injector is returned to the fine filter.
- A pressure relief valve is also provided for the safety of the system.

Fuel injection, Ignition and Engine performance

L-21

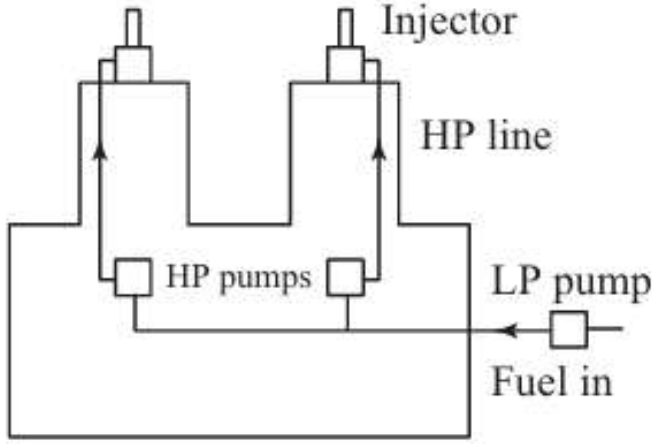
Individual Pump and Nozzle System

- In this system, each cylinder is provided with one pump and one injector. In this arrangement a separate metering and compression pump is provided for each cylinder. The pump may be placed close to the cylinder.
- The high pressure pump plunger is actuated by a cam, and produces the fuel pressure necessary to open the injector valve at the correct time. The amount of fuel injected depends on the effective stroke of the plunger.

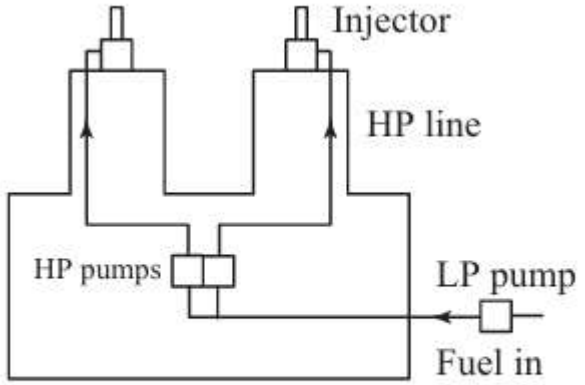
Fuel injection, Ignition and Engine performance

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Individual Pump and Nozzle System



(a) Individual pump and nozzle with separated pumps



(b) Individual pump and nozzle with pumps in cluster

Fuel injection, Ignition and Engine performai

L-21

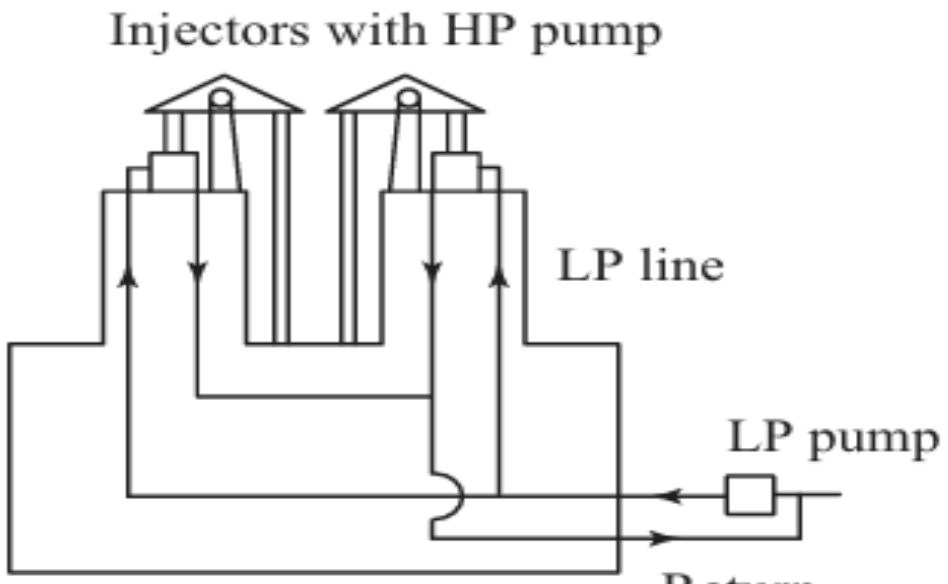
Unit Injector System

- pump and the injector nozzle are combined in one housing.
- Each cylinder is provided with one of these unit injectors.
- Fuel is brought up to the injector by a low pressure pump, where at the proper time, a rocker arm actuates the plunger and thus injects the fuel into the cylinder.
- The amount of fuel injected is regulated by the effective stroke of the plunger. The pump and the injector can be integrated in one unit

Fuel injection, Ignition and Engine performance

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Unit Injector System



(c) Unit injector system

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Fuel injection, Ignition and Engine performance

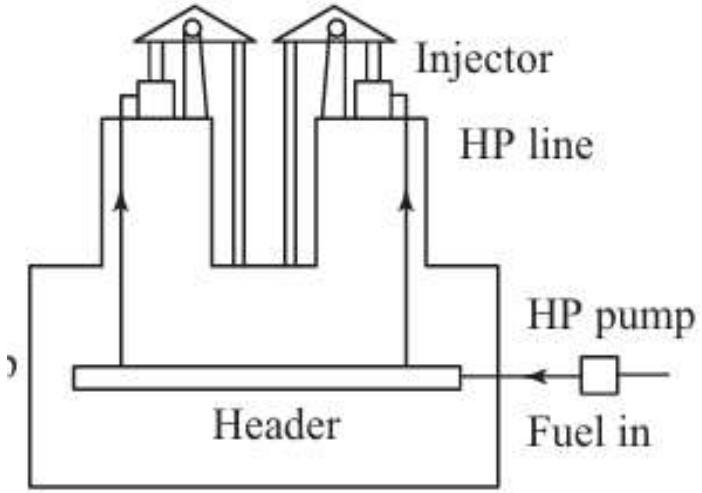
L-22 **Common Rail System (CRDI)**

- HP pump supplies fuel, under high pressure, to a fuel header. High pressure in the header forces the fuel to each of the nozzles located in the cylinders.
- At the proper time, a mechanically. operated (by means of a push rod and rocker arm) valve allows the fuel to enter the proper cylinder through the nozzle.
- The pressure in the fuel header must be that, for which the injector system was designed, i.e., it must enable to penetrate and disperse the fuel in the combustion chamber.
- The amount of fuel entering the cylinder is regulated by varying the length of the push rod stroke.
- A high pressure pump is used for supplying fuel to a header, from where the fuel is metered by injectors (assigned one per cylinder).

Fuel injection, Ignition and Engine performance

L-22

Common Rail System (CRDI)



(d) Common rail system

Fuel injection, Ignition and Engine performance

L-23

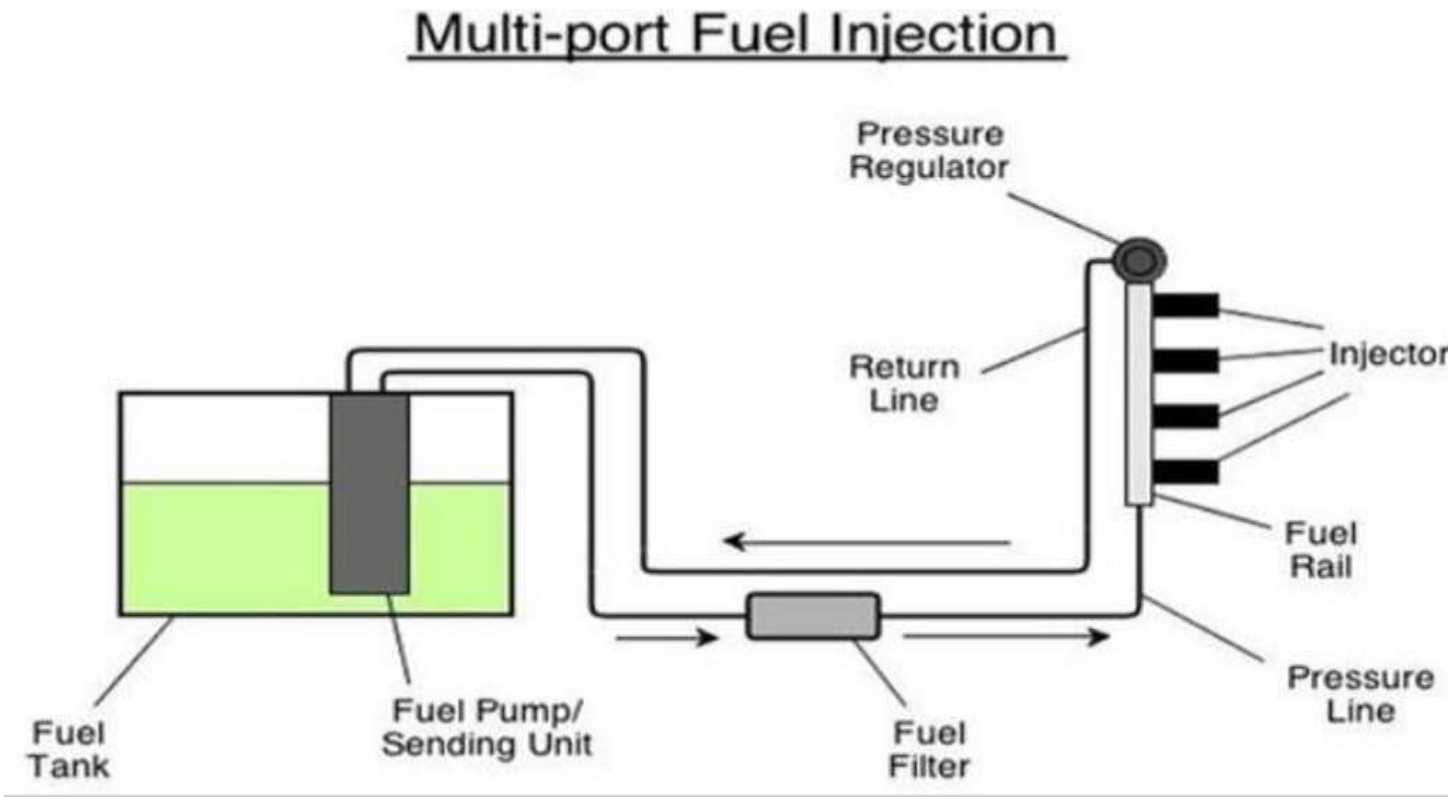
MPFI

- Multipoint fuel injection devotes a separate injector nozzle to each cylinder, right outside its intake port, which is why the system is sometimes called port injection.
- Shooting the fuel vapor this close to the intake port almost ensures that it will be drawn completely into the cylinder.
- The main advantage is that MPFI meters fuel more precisely than do TBI designs, better achieving the desired air-fuel ratio and improving all related aspects.

Fuel injection, Ignition and Engine performance

L-23

MPFI



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Fuel injection, Ignition and Engine performance

L-24 Electronic ignition system

The electronic Fuel injector system is consists of three different systems for the basicoperation of ECGIS 1. Fuel Delivery System 2. Air Induction system 3. Electronic Control System.

Fuel delivery system:

- The Fuel delivery system consists of Fuel tank, fuel pump, fuel filter, Fueldelivery pipe, fuel injector, fuel pressure regulator and fuel return pipe
- Fuel is delivered from the tank to the injector by means of an electric fuel pump. The pump is typically located in or near to the tank. Contaminants are filtered out by a high capacity in line fuel filter.
- Fuel is maintained at a constant pressure by means of a fuel pressure regulator. Any fuel which is not delivered to the intake manifold by the injector is returned to the tank through a fuel return pipe.

Fuel injection, Ignition and Engine performance

L-24 Electronic ignition system

Air induction system:

• The air induction system consists of the air cleaner, air flow metre, throttle valve, air intake chamber, intake manifold runner and intake valve.

• When the throttle valve is opened, air flows through the air cleaner, through the air flow meter (on L type system), pas the throttle valve and through a well-tuned intake manifold runner to the intake valve.

• Air delivered to the engine is a function of driver demand. As the throttle valve is opened firther, more air is allowed to enter the engine cylinders.

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Fuel injection, Ignition and Engine performa

L-24

Electronic ignition system

Electronic control System (ECS):

• The ECS consists of various engine sensors, Electronic control unit, Fuel injector assemblies and related wiring.

• The ECS determines precisely how much fuel needs to be delivered by the injector by monitoring the engine sensors.

• The ECS turns the injector for a precise amount of time, referred to as injection pulse width or injection duration, to deliver fuel so that proper air/fuel ratio is delivered to the engine.

Fuel injection, Ignition and Engine performan

L-24

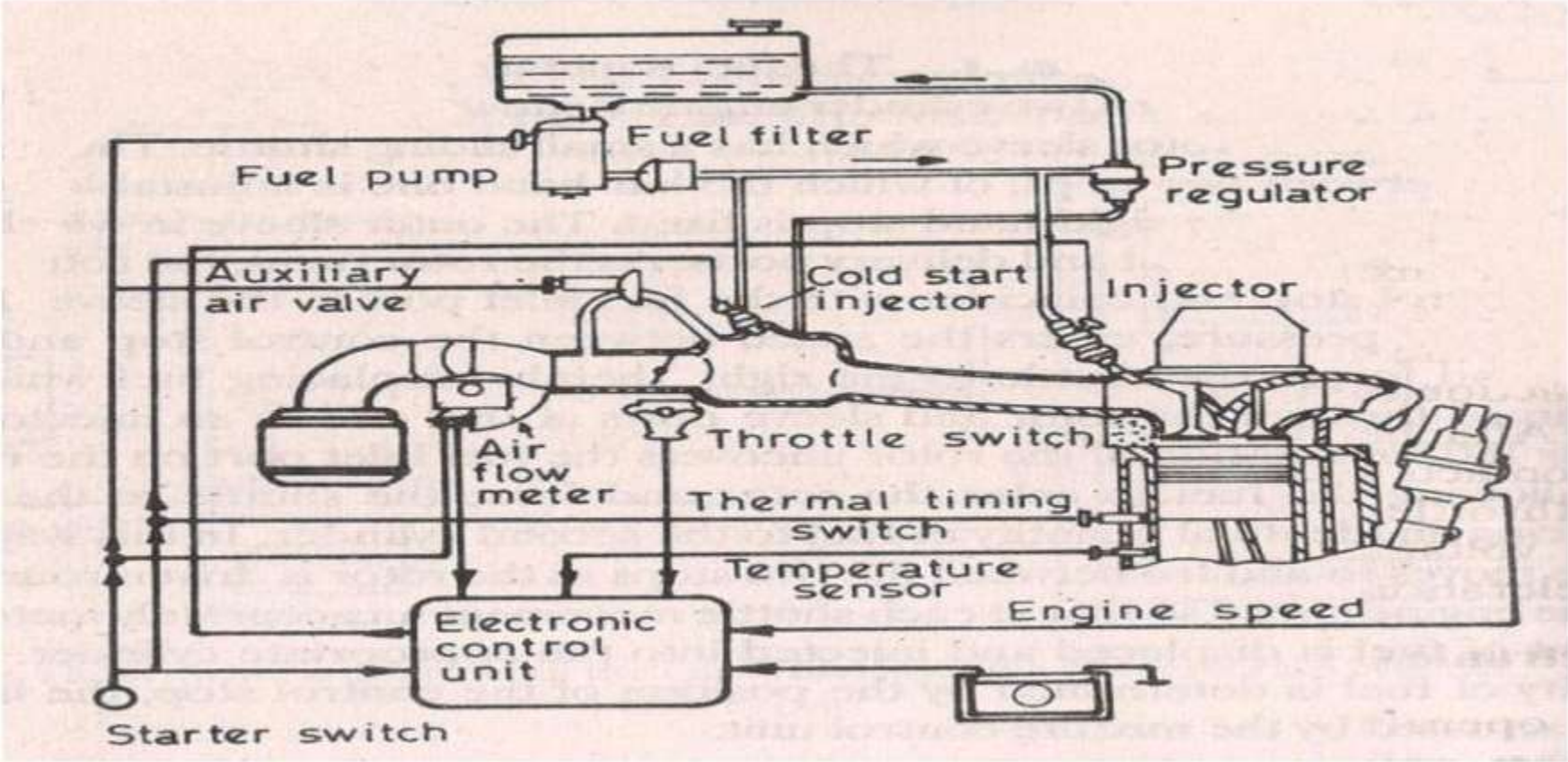
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Fuel injection, Ignition and Engine performance

L-24 Electronic ignition system



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Fuel injection, Ignition and Engine performance

L-25

Introduction to carburettors

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called a carburetor.

- Process of carburetion is influenced by

(i) the engine speed

(ii) the vapourization characteristics of the fuel

(iii) the temperature of the incoming air and

(iv) the design of the carbureto

Fuel injection, Ignition and Engine performance

L-25

Introduction to carburettors

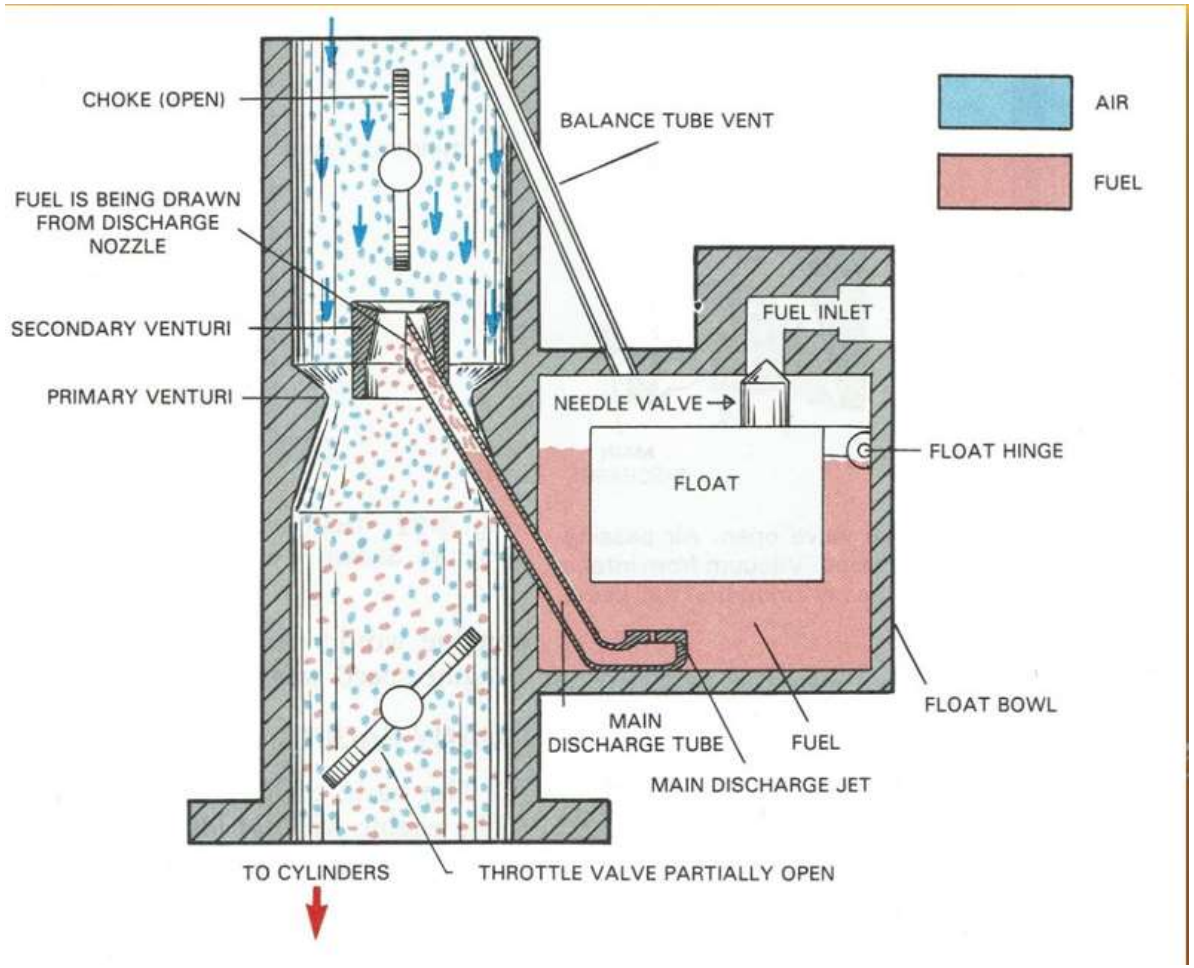
- Fuel enters the carburetor through a fuel inlet. The float regulates how much fuel to let in. When the float bowl has enough fuel the float moves up and shuts off the fuel via the needle valve. As the fuel level drops, the float drops down and allows the needle valve to open.
- As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum.
- As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum

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Fuel injection, Ignition and Engine performance

Introduction to carburettors

L-25



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Fuel injection, Ignition and Engine performance

L-25 Introduction to carburettors

A: F mixture:

An engine is generally operated at different loads and speeds. For this, proper air-fuel mixture should be supplied to the engine cylinder. Fuel and air are mixed to form three different types of mixtures.

Chemically correct mixture :Chemically correct or stoichiometric mixture is one in which there is just enough air for complete combustion of the fuel.

Rich mixture :A mixture which contains less air than the stoichiometric requirement is called a rich mixture (example, A/F ratio of 12:1, 10:1

Lean mixture: A mixture which contains more air than the stoichiometric requirement is called a lean mixture (example, A/F ratio of 17:1, 20:1

Fuel injection, Ignition and Engine performance

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L-26 **Testing of Engine:**

The basic performance parameters are the following :

- Power and Mechanical Efficiency.
- Mean Effective Pressure and Torque.
- Specific Output.
- Volumetric Efficiency.
- Fuel-air Ratio.
- Specific Fuel Consumption.
- Thermal Efficiency and Heat Balance.
- Exhaust Smoke and Other Emissions.
- Specific Weight.

Fuel injection, Ignition and Engine performance

L-26 **Testing of Engine:**

- **Brake power** :The power developed by an engine and measured at the output shaft is called the brake power (bp) and is given by,

$$bp = \frac{2\pi NT}{60}$$

where, T is torque in N-m and N is rotational speed in revolutions per minute.

- **Indicated Power:** It is the power developed in the cylinder. and thus, forms the basis of evaluation of combustion efficiency or the heat release in the cylinder.

$$IP = \frac{p_{im} LANk}{60}$$

- where, pm = Mean effective pressure, N/m2, L = Length of the stroke, m, A = Area of the piston, m2, N = Rotational speed of the engine, rpm (It is N/2 for four stroke engine), and k = Number of cylinders.

Fuel injection, Ignition and Engine performance

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L-26 Testing of Engine:

Specific Output Specific output of an engine is defined as the brake power (output) per unit of piston displacement and is given by,

$$\text{Specific output} = \frac{bp}{A \times L}$$

$$= \text{Constant} \times bmep \times rpm$$

Brake Specific Fuel Consumption :defined as the amount of fuel consumed for each unit of brake power developed per hour. It is a clear indication of the efficiency with which the engine develops power from fuel.

Fuel injection, Ignition and Engine performance

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L-26 Testing of Engine:

Thermal Efficiency and Heat Balance:Thermal efficiency of an engine is defined as the ratio of the output to that of the chemical energy input in the form of fuel supply. It may be based on brake or indicated output. It is the true indication of the efficiency with which the chemical energy of fuel (input) is converted into mechanical work.

$$\text{Brake thermal efficiency} = \frac{bp}{m_f \times C_v}$$

where, C_v = Calorific value of fuel, kJ/kg, and

m_f = Mass of fuel supplied, kg/sec.

Fuel injection, Ignition and Engine performance

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Testing of Engine:

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Fuel injection, Ignition and Engine performance

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Testing of Engine:

L-26

Heat Balance : The energy input to the engine goes out in various forms – a part is in the form of brake output, a part into exhaust, and the rest is taken by cooling water and the lubricating oil.

- The break-up of the total energy input into these different parts is called the heat balance.
- The main components in a heat balance are brake output, coolant losses, heat going to exhaust, radiation and other losses.
- Preparation of heat balance sheet gives us an idea about the amount of energy wasted in various parts and allows us to think of methods to reduce the losses so incurred.

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Unit 4

Engine emission and control

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- **Formation of carbon monoxide:**When there is not enough oxygen to convert all carbon to CO , some fuel does not get burned and some carbon ends up as CO. Typi cally the exhaust of an SI engine will be about 0.2 to 5% carbon monoxide. Not only is CO considered an undesirable emission, but it also represents lost chemical energy. CO is a fuel that can be combusted to supply additional thermal energy:

$$CO + \frac{1}{2} O_2 \rightarrow CO_2 + \text{heat}$$

- A well-designed SI engine operating under ideal conditions can have an exhaust mole fraction of CO as low as 0.001.

Engine emission and control

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Engine emission and control

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Formation of unburnt hydrocarbon:

- Figure shows the variation of HC emission levels with respect to equivalence ratio for an SI engine. It is evident that it is a strong function of air-fuel ratio.
- With a fuel-rich mixture there is not enough oxygen to react with all the carbon, resulting in high levels of HC and CO in the exhaust products. This is particularly true during starting, when the air-fuel mixture is purposely made very rich.
- It is also true to a lesser extent during rapid acceleration under load. If air-fuel ratio is too lean poorer combustion occurs, again resulting in HC emissions.
- The extreme of poor combustion for a cycle is total misfire. This occurs more often as air-fuel ratio is made leaner. One misfire out of 1000 cycles gives exhaust emissions of 1 gm/kg of fuel used.

Engine emission and control

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Formation of unburnt hydrocarbon:

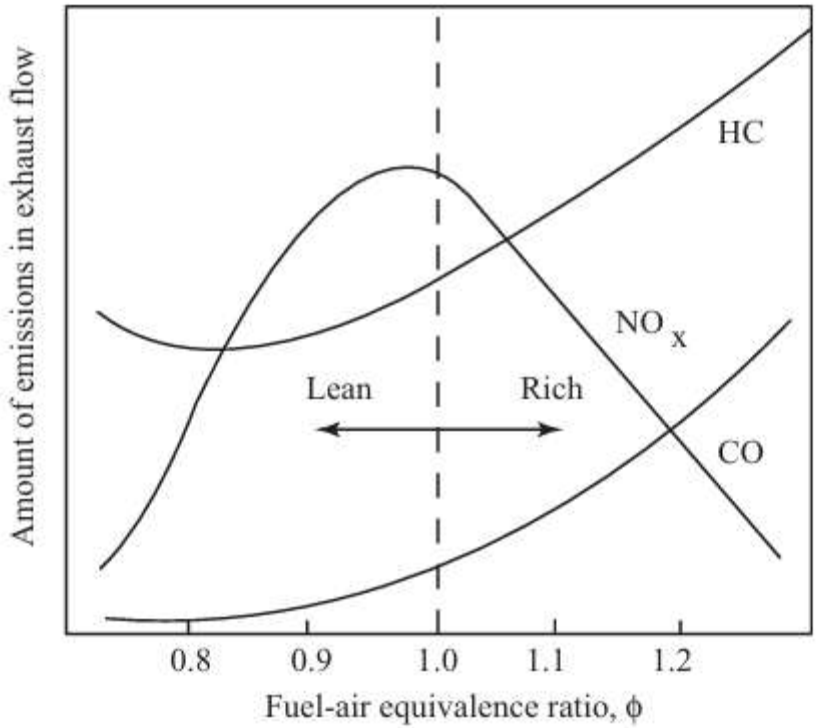
The causes for hydrocarbon emissions from SI engine are:

- Incomplete combustion
- Crevice volumes and flow in crevices
- Leakage past the exhaust valve
- Valve overlap
- Deposits on walls
- Oil on combustion chamber wall

Engine emission and control

L-27

Formation of unburnt hydrocarbon:



Engine emission and control

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Formation of oxides of nitrogen:

- NOx is formed by oxidation of molecular nitrogen.
- During combustion at high flame temperatures, nitrogen and oxygen molecules in the inducted air breakdown into atomic species which react to form NO.
- Some NO2 is also formed and NO and NO2 together are called as NOx.
- Exhaust gases of an engine can have up to 2000 ppm of oxides of Nitrogen.
- Most of this will be Nitrogen Oxide (NO) with a small amount of Nitrogen Dioxide (NO2).
- NOX is created mostly from nitrogen in air. Nitrogen can also be found in blends of fuel. All the restrictions are probably occurring during the combustion process and immediately after.

Engine emission and control

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Formation of oxides of nitrogen:These include but are not limited to:

$$O + N_2 \rightarrow NO + N$$
$$N + O_2 \rightarrow NO + O$$
$$N + OH \rightarrow NO + H$$

NO, in turn, can further react to form NO2 by various means including,

$$NO + H_2O \rightarrow NO_2 + H_2$$
$$NO + O_2 \rightarrow NO_2 + O$$

Engine emission and control

L-27

Formation of oxides of nitrogen:

- At low temperatures, atmospheric nitrogen exists as a stable diatomic molecule. Therefore, only very small trace amount of oxides of nitrogen are found.
- Significant amount of N is generated in the temperature range of 2500-3000K that can exist in an engine. The higher the combustion reaction temperature, the more diatomic nitrogen N2 will dissociate to monatomic nitrogen N, and more NOX will be formed.
- Although maximum flame temperature will occur at a stoichiometric air-fuel ratio. The maximum NOx is formed at a slightly lean equivalence ratio of about 0.95.
- The formation of NOX is also depends on pressure and air-fuel ratio.
- Combustion duration plays a significant role in NOX formation within the cylinder.
- Photochemical smog is formed by the photo chemical reaction of automobile exhaust and atmospheric air in the presence of sunlight.

Engine emission and control

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Formation of oxides of nitrogen:

$$NO_2 + Enenrgy\ from\ Sunlight \rightarrow NO + O + Smog$$

Monatomic oxygen is highly reactive and initiates a number of different reactions, one of which is formation of ozone:

$$O + O_2 \rightarrow O_3$$

- Ground level Ozone is harmful to lungs and other biological tissue.
- It is harmful to plants and trees and cause very heavy crop losses each year.
- Damage is also caused through reaction with rubber, plastics, and other materials.
- Ozone also results from atmospheric reactions with other engine emissions such as HC, aldehydes and other oxides of nitrogen.

Engine emission and control

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Formation of smoke and particulate matter:

- The exhaust of CI engines contains solid carbon soot particles that are generated in the fuel-rich zones within the cylinder during combustion.
- These are sees as exhaust smoke & cause undesirable odor pollution.
- Maximum density of particulate emissions occurs when the engine is under load at WOT.
- At this condition maximum fuel is injected to supply maximum power, resulting in a rich mixture & poor fuel economy
- . This can be seen in the heavy exhaust smoke emitted when a truck or railroad locomotive accelerates up a hill or from a stop.
- Particulates generation can be reduced by engine design & control of operating conditions, but quite often this will create other adverse results. However a longer combustion time means a high cylinder temperature and more NOX generation.
- Dilution with EGR lowers NOX emissions but increases particulates and HC emissions
- The first four are the common in both SI & CI engines and the last two are mainly from CI engines.

Engine emission and control

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Formation of smoke and particulate matter:

- Carbon spheres are generated in the combustion chamber in the fuel-rich zones where there is not enough oxygen to convert all carbon to CO 2.

$$C_x\ H_y + z\ O_2 \rightarrow a\ CO_2 + b\ H_2\ O + cCO + dC(s)$$

- Then, as turbulence and mass motion continue to mix the components in the combustion chamber, most of these carbon particles [C(s)] find sufficient oxygen to further react and are converted to CO2

$$C(s) + O_2 \rightarrow CO_2$$

Engine emission and control

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Methods of controlling emissions:

Emission control options can be grouped into three categories:

- Engine design techniques,
- Fuel and lubricant related technologies,
- Exhaust gas after treatment.

Engine emission and control

Methods of controlling emissions:

Engine design techniques

- Fuel injection

Implementation of systems capable of variable injection timing through the use of electronic controls.

- Injection timing:

Affects combustion phasing; retarding the combustion phasing can be used to limit NOx emissions.

- Injection pressure

Higher injection pressure can lower soot emissions; especially important when combined with NOx control technologies such as EGR

Engine emission and control

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Methods of controlling emissions**:**

Engine design techniques

- Multiple injections

Multiple injections strategies have been developed to lower NOx, soot, HC and CO emissions.

- Exhaust gas recirculation (EGR)

In diesel engines, primary application is to control NOx emissions

- Intake boosting

Higher intake pressure increases air/fuel ratio for given fuel injection amount and lowers soot production

- Combustion chamber design

Combustion chamber design changes are commonly used to offset increases in soot emissions when measures are taken to limit NOx emissions. In many cases, improvements enhance mixing late in the combustion process to improve soot burn-out.

Engine emission and control

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Methods of controlling emissions:

Fuel & lubricant technologies

- Lubricating oil

Low viscosity lubricants are important for fuel consumption/CO_2 reductions but require other changes to ensure engine wear levels do not increase.

- Alternative fuels

Primary impact is life-cycle CO_2 emissions

- Fuel additives

Cetane additives help ensure consistent and reliable ignition quality of modern diesel fuels to ensure reliable and predictable performance; injector cleanliness additives and lubricity additives are intended to keep fuel injection system components clean and reduce wear to ensure long term durability and consistent performance of fuel injection systems; some diesel particulate filter systems use fuel additives to assist particulate filter regeneration.

Engine emission and control

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Engine emission and control

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Methods of controlling emissions:

Exhaust aftertreatment technologies

Catalytic Convertor System (CAT) for CO,HC and Nox :

- A “Catalytic Converter System” is an emission control device that converts toxic gases and pollutants in exhaust gas to less toxic pollutants by causing a redox reaction (an oxidation and a reduction reaction) in the presence of catalysts.
- The catalyst material is typically a combination of precious metals such as Platinum, Rhodium and Palladium.
- Catalytic converters are used with internal combustion engines fuelled by either petrol (gasoline) or diesel including lean-burn engines as well as kerosene heaters and stoves.

Engine emission and control

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Methods of controlling emissions:

Exhaust aftertreatment technologies

Catalytic Convertor System (CAT) for CO,HC and Nox :

Oxidation Catalyst

The oxidation catalyst consists of ***Platinum and Palladium.*** The oxidation catalyst converts CO and HC to CO_2 and H_2O by combining with oxygen as per following chemical reaction: -

$$2CO + O_2 = 2CO_2$$

$$C_xH_{4x} + 2xO_2 = xCO_2 + 2xH_2O$$

Reduction Catalyst

The reduction catalyst consists of ***Platinum and Rhodium.*** The reduction catalyst converts NO_x to N_2 and O_2 by removing oxygen as per following chemical reaction: -

$$xNO_x = N_x + xO_x$$

Engine emission and control

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Methods of controlling emissions:

Types of Catalytic Convertors

Catalytic Convertor System (CAT) for CO,HC and Nox :

- 2-Way Catalytic Convertor removes the CO and HC components (2- components only) through oxidation to form carbon dioxide and water
- 3-way catalytic convertor removes all the three pollutants i.e. HC, CO and NOx by redox reactions.
- The catalyst is coated on Aluminium Oxide substrate through which exhaust gas passes.
- The core is placed inside a stainless-steel wire mesh for protection against mechanical damage and thermal shocks caused by temperature extremes.
- The convertor is provided with a heat shield to limit the surface temperature to safe values. It is also provided with an oxygen sensor to measure oxygen content in exhaust gas which is provided as an input to ECU for controlling the air-fuel ratio and activating other engine management controls.
- The first set catalyst is the “Reduction Catalyst (Platinum – Rhodium)” which removes NOx and releases nitrogen and oxygen.
- This oxygen along with HC and CO passes on to the second set catalyst which is the “Oxidation Catalyst (Platinum – palladium)”. This catalyst then oxidises them to carbon dioxide and water

Engine emission and control

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Methods of controlling emissions:

Types of Catalytic Convertors

Catalytic Convertor System (CAT) for CO,HC and Nox :

Functions

A three-way catalytic converter has three simultaneous functions:

1. Reduction of nitrogen oxides into elemental nitrogen and oxygen:

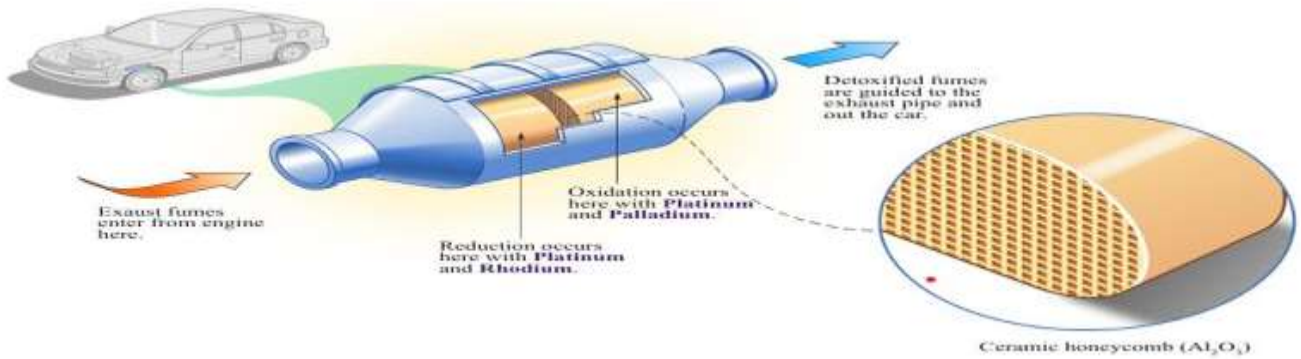
$$NO_x \rightarrow N_x + O_x$$

2. Oxidation of carbon monoxide to carbon dioxide:

$$CO + O_2 \rightarrow CO_2$$

3. Oxidation of hydrocarbons into carbon dioxide and water:

$$C_xH_{4x} + 2x\,O_2 \rightarrow x\,CO_2 + 2x\,H_2O$$



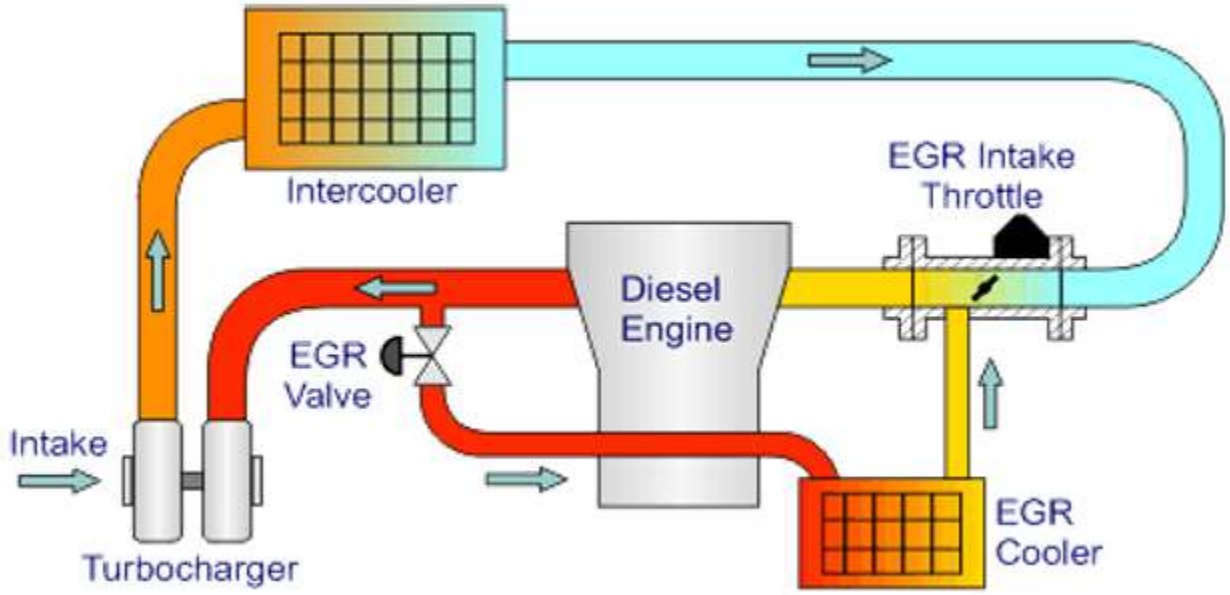
Engine emission and control

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Methods of controlling emissions:

Exhaust Gas Recirculation System (EGR)



Engine emission and control

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Methods of controlling emissions:

Exhaust Gas Recirculation System (EGR)

- Some of the exhaust gas (about 6 ~ 13%) to the intake manifold under certain conditions.
- This type of arrangement increases the proportion of inert gases (e.g. Carbon dioxide, Water vapour and Nitrogen) in the air entering the cylinders, thus lowering the peak combustion temperature which suppresses the generation of NOx.

Engine emission and control

L-31

Methods of controlling emissions:

Selective Catalytic Reduction (SCR)

- SCR is an advanced active emissions control technology system that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine.
- The reductant source is usually “Automotive-grade Urea, otherwise known as Diesel Exhaust Fluid (DEF).
- The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide (CO2), natural components of the air we breathe, which is then expelled through the vehicle tailpipe.

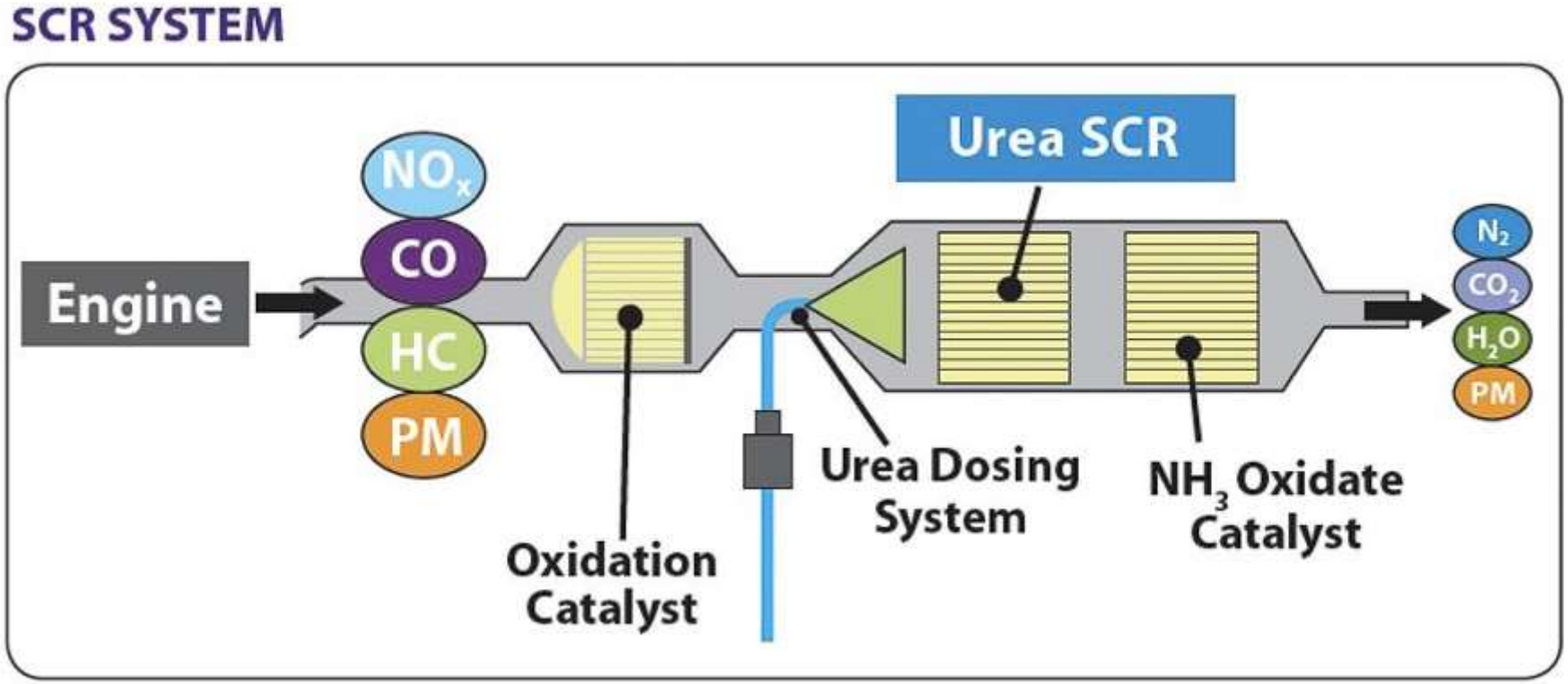
Engine emission and control

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Methods of controlling emissions:

Selective Catalytic Reduction (SCR)



Engine emission and control

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Methods of measurement: The various emission are measured usin following sensors and methods

Emission Species	Method
CO	NDIR (Non-Dispersive Infra-Red)
CO2	NDIR (Non-Dispersive Infra-Red)
O2	PMD
NOx	CLD (Chemiluminescence)
THC	FID (Flame-Ionisation Detector)

Engine emission and control

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Emission norms:Emission standards for 2- and 3-wheel vehicles through stage BS III are summarized in the following table

Date	Stage	CO	HC	HC+NOx	PM
2-Wheel Gasoline Vehicles					
1991		12-30	8-12	-	-
1996		4.50	-	3.60	-
2000	BS I	2.00	-	2.00	-
2005.04	BS II	1.5	-	1.5	-
2010.04	BS III	1.0	-	1.0	-
3-Wheel Gasoline Vehicles					
1991		12-30	8-12	-	-
1996		6.75	-	5.40	-
2000	BS I	4.00	-	2.00	-
2005.04	BS II	2.25	-	2.00	-

Engine emission and control

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Emission norms:Emission standards for 2- and 3-wheel vehicles through stage BS III are summarized in the following table

2010.04	BS III	1.25	-	1.25	-
2- and 3-Wheel Diesel Vehicles					
2005.04	BS II	1.00	-	0.85	0.10
2010.04	BS III	0.50	-	0.50	0.05

Engine emission and control

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Emission norms:Emission standards for 2- and 3-wheel vehicles through stage BS III are summarized in the following table

Bharat Stage VI Standards

Bharat Stage VI standards for 2- and 3-wheeled vehicles were proposed in February 2016

Proposed BS VI emission standards for 2- and 3-wheel vehicles, g/km

Date	Stage	Type	CO	HC	NMHC	NOx	PM
2-Wheel Vehicles (new models only)							

https://dieselnet.com/standards/in/2wheel.php#bs6 3/4

9/26/25, 11:06 AM Emission Standards: India: 2- and 3-Wheel Vehicles

2020.04	BS VI	SI	1.0	0.10	0.068	0.06	0.0045*
		CI	0.50	0.10	0.068	0.09	0.0045
3-Wheel Vehicles (all models)							
2020.04	BS VI	SI	0.44	0.35	-	0.085	-
		CI	0.22	0.10	-	0.10	0.025
* Gasoline direct injection only							

The BS VI regulation also includes emission standards for 2-wheelers with an SI engine and $D \leq 50$ cc and $V \leq 50$ km/h

CO = 0.50 g/km

HC = 0.35 g/km

NOx = 0.15 g/km

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Unit 5

Alternates fuels for IC Engines

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Biodiesel

- Biodiesel (mono alkyl esters) is a cleaner burning diesel fuel made from natural, renewable sources such as vegetable oils.
- Biodiesel operates in compression ignition engines like petroleum diesel thereby requiring no essential engine modifications.
- Biodiesel is a renewable fuel that is produced from a variety of edible and nonedible vegetable oils and animal fats.
- Biodiesel can be produced through a transesterfication process, forming fatty esters. One of the by-products of production is glycerol, which can then be sold as an independent product.

Alternates fuels for IC Engines

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Biodiesel Advantages:

- Biodiesel is the only alternative fuel that runs in any conventional, unmodified diesel engine.
- Needs no change in refueling infrastructures and spare part inventories. Maintains the payload capacity and range of conventional diesel engines.
- Diesel skilled mechanics can easily attend to biodiesel engines.
- 100% domestic fuel.
- Neat biodiesel fuel is non-toxic and biodegradable. Based on Ames Mutagenicity tests, biodiesel provides a 90% reduction in cancer risks.
- Cetane number is significantly higher than that of conventional diesel fuel.

Alternates fuels for IC Engines

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Biodiesel Disadvantages:

- Quality of biodiesel depends on the blend thus quality can be tampered.
- Biodiesel has excellent solvent properties. Any deposits in the filters and in the delivery systems may be dissolved by biodiesel and result in need for replacement of the filters.
- There may be problems of winter operatibility.
- Spills of biodiesel can decolorize any painted surface if left for long.
- Neat biodiesel demands compatible elastomers

Alternates fuels for IC Engines

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Ethanol:

Ethanol (CH3CH2OH) is a group of chemical compounds whose molecule contains a hydroxyl group, -OH, bonded to a carbon atom.

Ethanol made from cellulosic biomass materials instead of traditional feedstock (starch crops) is called bioethanol.

Production of Ethanol: It can be produced by fermentation of vegetables and plant materials. In India, its main source is molasses - a by-product of sugarcane. It‘s done in three stages

1. Extraction of juice from sugarcane
2. Fermentation of the juice
3. Distillation bio ethanol.

Alternates fuels for IC Engines

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Ethanol:

Advantages

- Decreased emissions of CO .
- Decreased emissions of HC
- Decrease in non-regulated toxics: 1-3 butadiene decrease benzene decrease toluene decrease and xylene decrease
- Increase in non-regulated toxics: acetaldehyde increase and formaldehyde increase

Alternates fuels for IC Engines

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Ethanol:

Disadvantages

- Major problem with ethanol is the corrosion. Ethanol driven vehicles require lines, hoses and valves to be resistant to the corrosion that alcohol can induce. Alcohol corrodes lead-plated fuel tanks; magnesium, copper, lead, zinc, and aluminium parts; and some synthetic gaskets.

Alternates fuels for IC Engines

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Hydrogen:

- Hydrogen is characterized by having the highest energy content per mass of all chemical fuels at 120.2 MJ/kg. . In terms of mass energy, it exceeds fossile by 2.8 times, and alcohols by five to six times. Therefore, hydrogen fuel can increase the effective efficiency of an engine and help reduce specific fuel consumption.
- Volumetric basis, due to its lower volumetric energy density, liquid hydrogen may require four times more space than oil or about two times more space than liquefied natural gas (LNG) for an equivalent amount of carried energy.
- Hydrogen requires low temperatures below -253° C (-423.4° F) to liquefy. Due to this very low temperature, the required volume to store liquid hydrogen could be even higher when considering the necessary layers of materials or vacuum insulation for cryogenic storage and other structural arrangements.
- Due to the challenges related to low temperature or high-pressure storage, hydrogen can alternatively be carried within other substances such as ammonia or methanol.
- Hydrogen may also be co-combusted with diesel fuel, and depending on the proportions used, reductions of nitrogen oxide (NOx) emissions may require the use of exhaust gas after treatment technologies. Other minor modifications in engine timing and control systems may be required to achieve optimum engine performance.

Alternates fuels for IC Engines

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Hydrogen:

Advantages

- Carbon and sulfur free
- Can be produced renewably from electrical energy and bio-renewable processes
- Can be stored and transported as a liquid or gas
- Established commercial product on land
- Gaseous, particulate matter and GHG free emissions with fuel cells •
- Highly buoyant and disperses if leaked, even at liquid hydrogen temperatures.

Alternates fuels for IC Engines

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Hydrogen:

Disadvantages

- Possible high fuel cost
- Low availability of renewably produced hydrogen
- Fuel infrastructure and bunkering need investment
- Novel power generation systems will require more technology innovation and cost reductions
- High explosion risk in confined spaces
- Low cryogenic temperature challenges (storage,management, leaks, etc.)
- Material challenges (permeability, hydrogen embrittlement, etc.)
- NOx emissions if burning hydrogen in internal combustion engines.

Alternates fuels for IC Engines

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Hydrogen: Properties of Hydrogen

		HYDROGEN
Boiling Temperature (° C)*		-253
Liquid Density (kg/m³)*		70.8
Gas Density (kg/m³)** (Air: 1.198)		0.084
Dynamic Viscosity (g/cm·s x 10-6)	Gas	8.8
	Liquid	13.49
Flame Temperature in Air (° C)		2396
Maximum Burning Velocity (m/s)		3.15
Heat of Vaporization (J/g)*		448.7
Lower Flammability Limit (% vol. fraction)***		4.0
Upper Flammability Limit (% vol. fraction)***		75.0
Minimum Ignition Energy (mJ)***		0.017
Auto-ignition Temperature (° C)		585
Temperature at Critical Point (K)		33.19****
Pressure at Critical Point (kPaA)		1297

Alternates fuels for IC Engines

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Compressed Natural Gas (CNG):

Petroleum and natural gas are obtained by the process of drilling wells. As already known crude petroleum is composed of hydrocarbon.

CNG is made by compressing natural gas (which is mainly composed of methane, CH4), to less than 1 percent of the volume it occupies at standard atmospheric pressure. It is stored and distributed in hard containers at a pressure of 20–25 MPa , usually in cylindrical or spherical shapes.

ADVANTAGES

CNG-powered vehicles have lower maintenance costs than other hydrocarbon fuel-powered vehicles. CNG fuel systems are sealed, preventing fuel losses from spills or evaporation. Increased life of lubricating oils, as CNG does not contaminate and dilute the crankcase oil. Being a gaseous fuel, CNG mixes easily and evenly in air

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Liquefied Petroleum Gas (LPG):

Propane and butane are obtained from oil and gas wells. They are also the products of the petroleum refining process. For automobile engines, two types of LPG are used. One is propane and the other is butane. Sometimes, a mixture of propane and butane is used as liquid petroleum gas in automobile ,

Advantages

LPG contains less carbon than petrol. LPG powered vehicle produces 50 per cent less carbon monoxide per kilometre, though only slightly less nitrogen compounds. Therefore emission is much reduced by the use of LPG. LPG has high antiknock characteristics.

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Homogenous Charge Compression Ignition Engine

The Homogeneous Charge Compression Ignition (HCCI) engine is often described as a hybrid between the spark ignition engine and the diesel engine. The blending of these two designs offers diesel-like high efficiency without the difficult—and expensive—to deal with NOx and particulate matter emissions.

REQUIREMENTS FOR HCCI

The HCCI combustion process puts two major requirements on the conditions in the cylinder:

- The temperature after compression stroke should equal the auto-ignition temperature of the fuel/air mixture.
- The mixture should be diluted enough to give reasonable burn rate.

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Homogenous Charge Compression Ignition Engine

Advantages, including:

- Lower combustion temperatures that significantly reduce nitrogen oxide (NOx) emissions
- Near-complete combustion that minimizes hydrocarbon (HC) and carbon monoxide (CO) emissions
- Reduced pumping losses and higher compression ratios that improve thermal efficiency
- Fuel flexibility that accommodates various fuel types and qualities

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Homogenous Charge Compression Ignition Engine

Disadvantages At high loads,

HCCI operation becomes difficult due to:

- Excessive pressure rise rates leading to engine knock
- Higher NOx emissions as temperatures increase
- Potential mechanical damage from extreme pressure peaks

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Flex Engine

Flex-fuel vehicles are defined as vehicles capable of operating on multiple fuels or fuel blends, primarily gasoline and alternative fuels like ethanol and methanol. They utilize a processor to detect the fuel blend and automatically adjust the engine parameters for optimal performance.

Advantages

1. Flex Fuel Engines are undoubtedly good for our environment. Because Ethanol usually burns cleaner than Gasoline and leaves less toxic fumes into the atmosphere.
2. with unique features like Fuel Composition Sensor, FFVs can burn any fuel mixture, and ECM can easily adjust the fuel injection process.
3. FFVs promotes sustainability. As Flex Fuel Engines runs on Ethanol, and we can obtain Ethanol from natural crops such as Corn and Sugarcane.

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Flex Engine

Disadvantages

1. Ethanol can easily absorb ordinary dirt or dust, potentially resulting in damaging your vehicle's engine.
2. FFVs have a pretty low gas mileage than regular vehicles.

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Gasoline Direct Injection engines

Gasoline Direct Injection engines, are defined as internal combustion engines that inject fuel directly into the combustion chamber, allowing for improved thermal efficiency, reduced in-cylinder temperatures, and the capability for ultra-lean combustion, which enhances fuel economy while presenting challenges in exhaust emissions control,

Advantages:

- Easier cold starts.
- Better fuel economy and lower emissions due to better fuel atomization.
- Works well with E85 flex fuel, which is a high-level combination of ethanol and gasoline.
- Reduced turbo lag on turbocharged engines.
- Fuel acts as a coolant, allowing for higher compression ratios.

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Gasoline Direct Injection engines

Disadvantages:

- Dirtier intake valves (no fuel flows across them to keep them clean).
- Harder to increase fuel flow for high-performance applications.
- Designed for fuel pressure, not high flow.
- Can lack power and efficiency at high RPMs.
- More advanced compared with a regular injection engine, making for more complex repairs and expense during installation.

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L-38 Gasoline Direct Injection engines



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RCCI

- RCCI uses in-cylinder fuel blending with at least two fuels of different reactivity and multiple injections to control in-cylinder fuel reactivity to optimize combustion phasing, duration and magnitude.
- The process involves introduction of a low reactivity fuel into the cylinder to create a well-mixed charge of low reactivity fuel, air and recirculated exhaust gases.
- The high reactivity fuel is injected before ignition of the premixed fuel occurs using single or multiple injections directly into the combustion chamber.
- Examples of fuel pairings for RCCI are gasoline and diesel mixtures, ethanol and diesel, and gasoline and gasoline with small additions of a cetane-number booster (di-tert-butyl peroxide (DTBP)).

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RCCI

Advantages

- Lowered NOx and PM emissions
- Reduced heat transfer losses
- Increased fuel efficiency
- Eliminates need for costly after-treatment systems
- Complies with EPA 2010 emissions guidelines without exhaust after treatment

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Multi Fuels Engines

- to the ability to operate on various fuels, such as biofuels, hydrogen, natural gas, or synthetic fuels, these engines enable greater operational flexibility and additionally reduce the emission of harmful substances.
- The introduction of alternative fuels allows for the reduction of CO2, NOx and particulate emissions, which is of significant importance in terms of the applicable exhaust emission standards and reducing exposure to air pollutio

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Fuel cell

- A fuel cell is an electrochemical device that uses reverse electrochemical reactions and continuously converts the chemical energy content of the fuel into electrical energy, water, and some heat as long as fuel and oxidant are supplied.
- A fuel cell is a power generation engine that takes fuels like hydrogen and oxygen as inputs and converts their chemical energy content directly into electrical energy through electrochemical reactions, producing water and heat as the by-products as shown in Figure .
- A fuel cell consists of two electrodes separated by an electrolyte medium, which avoids direct contact of hydrogen and oxygen and direct chemical combustion as shown in a general schematic diagram

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Fuel cell

Anode reaction: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode reaction: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall reaction: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

