ME 430 Internal Combustion Engines

Engineering Fundamentals of Internal Combustion Engines

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Lecture Notes for the Undergraduate Course

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Chapter 1
Introduction

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CONTENTS

- Introduction
- Early History
- Engine Classifications
- Terminology and Abbreviations
- Main Engine Components
- Basic Engine Cycles
- Engine Emissions and Air Pollution
- Summary

INTRODUCTION

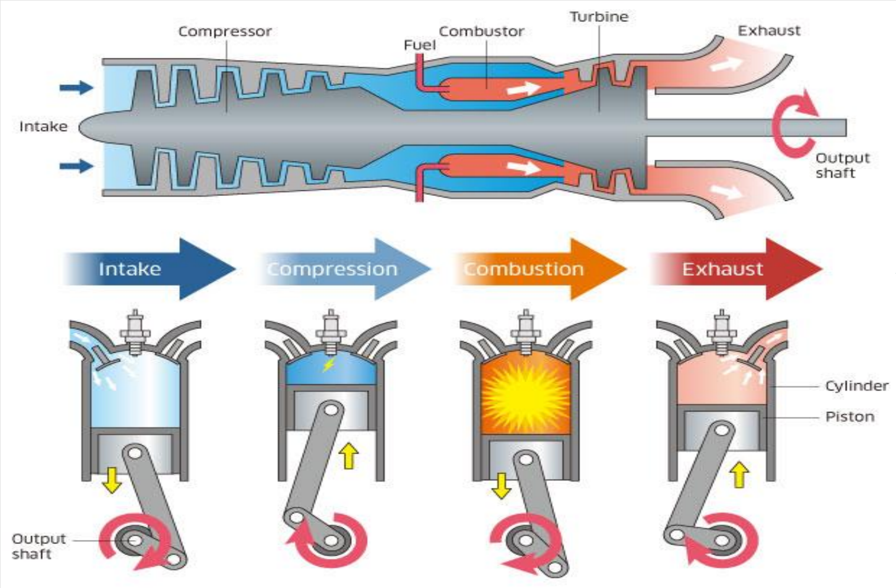
Heat engine:

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

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

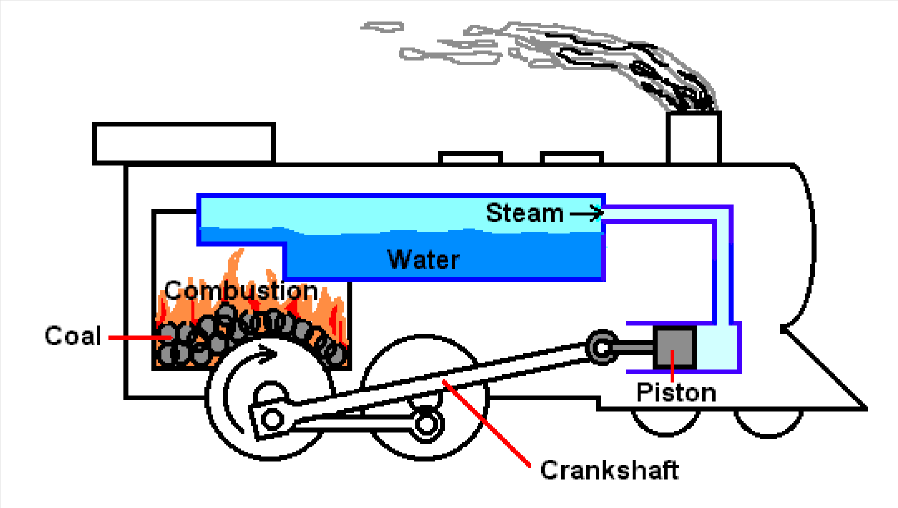
INTRODUCTION

Difference Between Internal and External Combustion Engine



In an internal combustion engine, <u>the fuel is burned directly within the engine cylinder,</u> and the hot combustion gases expand and push the piston, creating mechanical work.

Gas turbines operate similarly, with the key difference being that they use a <u>continuously rotating turbine instead of a reciprocating piston</u>. However, the **combustion still happens directly within the engine**, making them internal combustion engines.



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

INTRODUCTION

Difference Between Internal and External Combustion Engine

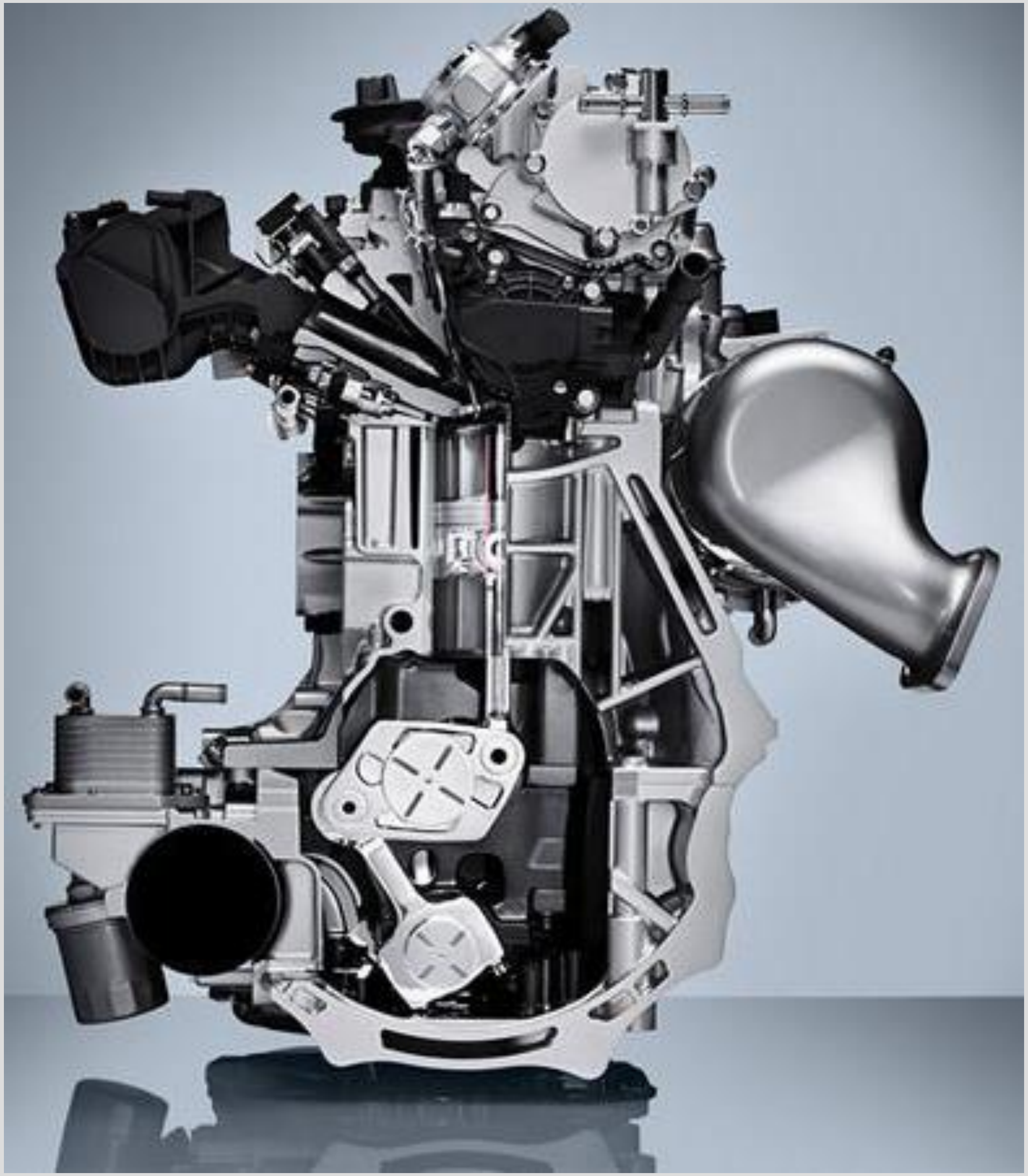
Feature	**Internal Combustion Engine**	**External Combustion Engine**
Combustion Location	Inside the engine cylinder	Outside the engine in a separate chamber
Heat Transfer	Hot gases directly expand pistons, creating mechanical work	Heat used to expand a working fluid, (like steam or air), which then expands and drives a turbine or piston, creating mechanical work.
Fuel Type	Typically gasoline, diesel, or other fossil fuels	Wider range of fuels, including renewable sources
Design	Compact and lightweight	Bulkier and heavier
Applications	Transportation (cars, motorcycles, airplanes, jet engines (excluding EFGTs), lawnmowers, chainsaws.)	Industrial power generation, Steam engines (locomotives, early ships), Stirling engines (generators, solar power), some rocket engines (not all).
Advantages	High power output, compact size, higher efficiency (35-40%)	Cleaner emissions, wider fuel options
Disadvantages	Higher emissions, limited fuel options, complex design	Lower power output and efficiency, bulky design, potential heat loss

INTRODUCTION

Internal Combustion Engine

In this engine, the combustion of air and fuels **take place inside the cylinder** and are used as **the direct motive force**.

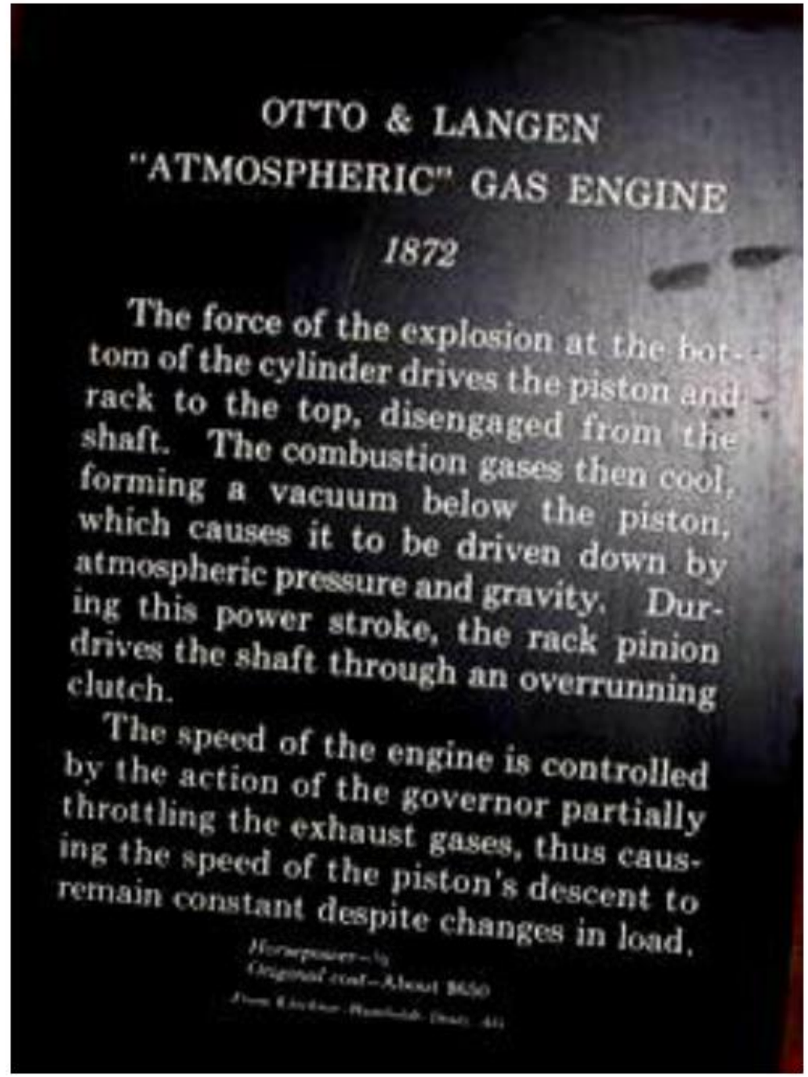
Most internal combustion engines are reciprocating engines having pistons that reciprocate back and forth in cylinders internally within the engine. This course concentrates on the thermodynamic study of this type of engine.



HISTORY OF ENGINES

- Huygens (1673) developed piston mechanism
- Hautefeuille (1676) first concept of internal combustion engine
- Papin (1695) first to use steam in piston mechanism
- “Modern” engines using same principles of operation as present engines – previously no compression cycle
- Lenoir (1860) driving the piston by the expansion of burning products - first practical engine, 0.5 hp, mech efficiency up to 5%
- Rochas (1862) four-stroke concept was proposed
- Otto – Langen (1867) produced various engines, 11% efficiency
- Otto (1876) Four-stroke engine prototype built, 8 hp
- Clark (1878) Two-stroke engine was developed
- Diesel (1892) Single cylinder, compression ignition engine

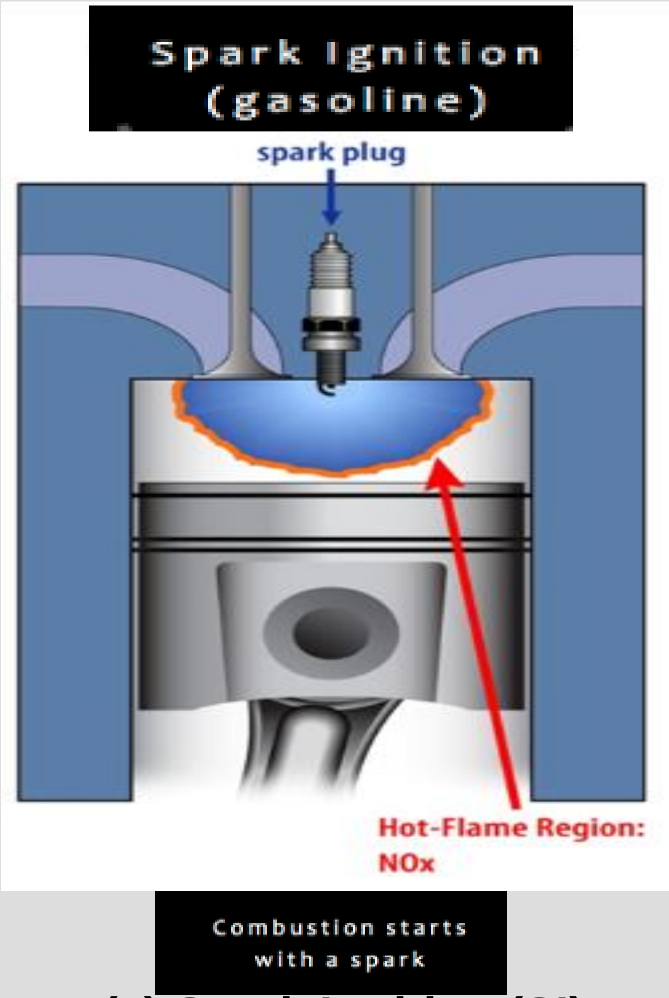
HISTORY OF ENGINES



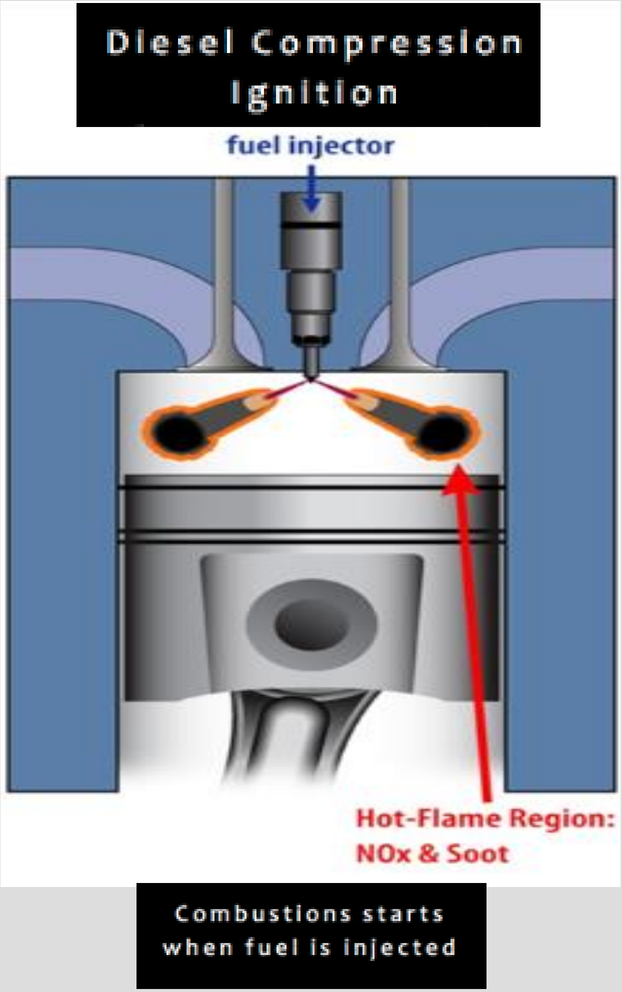
ENGINE CLASSIFICATIONS

Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition



(a) Spark Ignition (SI).



(b) Compression Ignition (CI).

ENGINE CLASSIFICATIONS

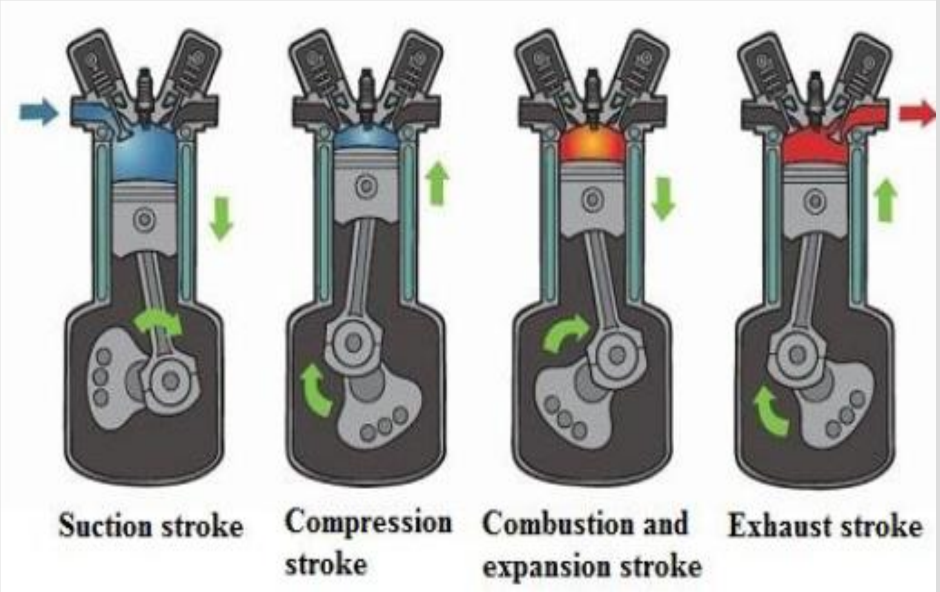
Internal combustion engines can be classified in a number of different ways:

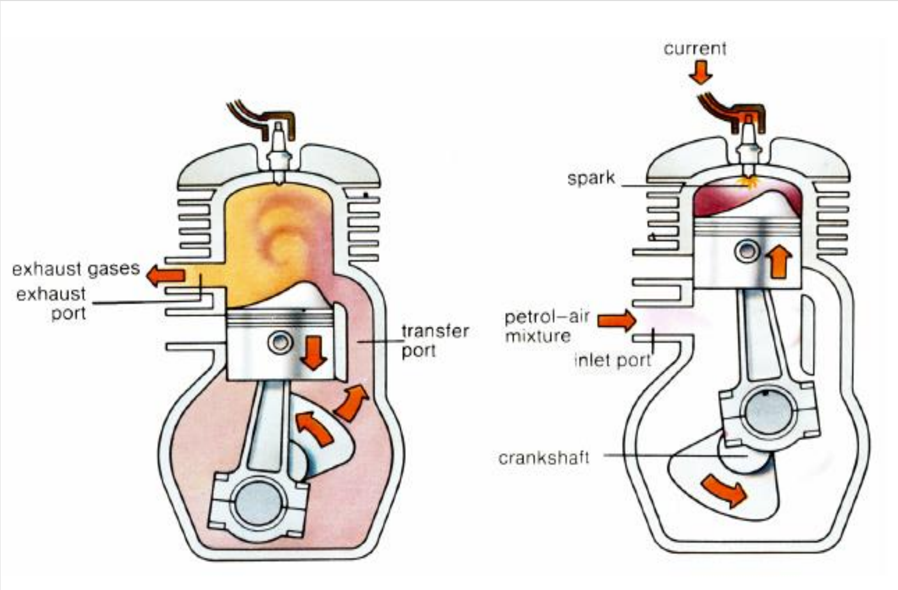
Comparison of SI and CI engine	
SI Engine	**CI Engine**
Working cycle is Otto cycle	Working cycle is Diesel cycle
Petrol, gasoline or high octane fuel is used	Diesel or high cetane fuel is used
Air-Fuel mixture ratio:14.7:1	Air-Fuel mixture ratio: 20:1 to 70:1
Typical compression ratio 8:1 to 12:1	Typical compression ratio 12:1 to 24:1
Fuel mixed with air prior entering the cylinder	Fuel mixed with air while in the cylinder (High pressure fuel injection)
Spark ignition of air-fuel mixture	Compression ignition of air-fuel mixture
Engine speed range 500 to 8000	Engine speed range 500 to 6000
Maximum torque at mid speed range	Maximum torque at lower speed range
Load control - quantity of Air-Fuel mixture (Using a throttle)	Load Control - "strength" of Air-Fuel mixture (Amount of Fuel)
High self-ignition temperature	Low self-ignition temperature
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency lower due to higher compression ratio

ENGINE CLASSIFICATIONS

Internal combustion engines can be classified in a number of different ways:

2. Engine Cycle





(a) Four-Stroke Cycle.

(b) Two-Stroke Cycle.

ENGINE CLASSIFICATIONS

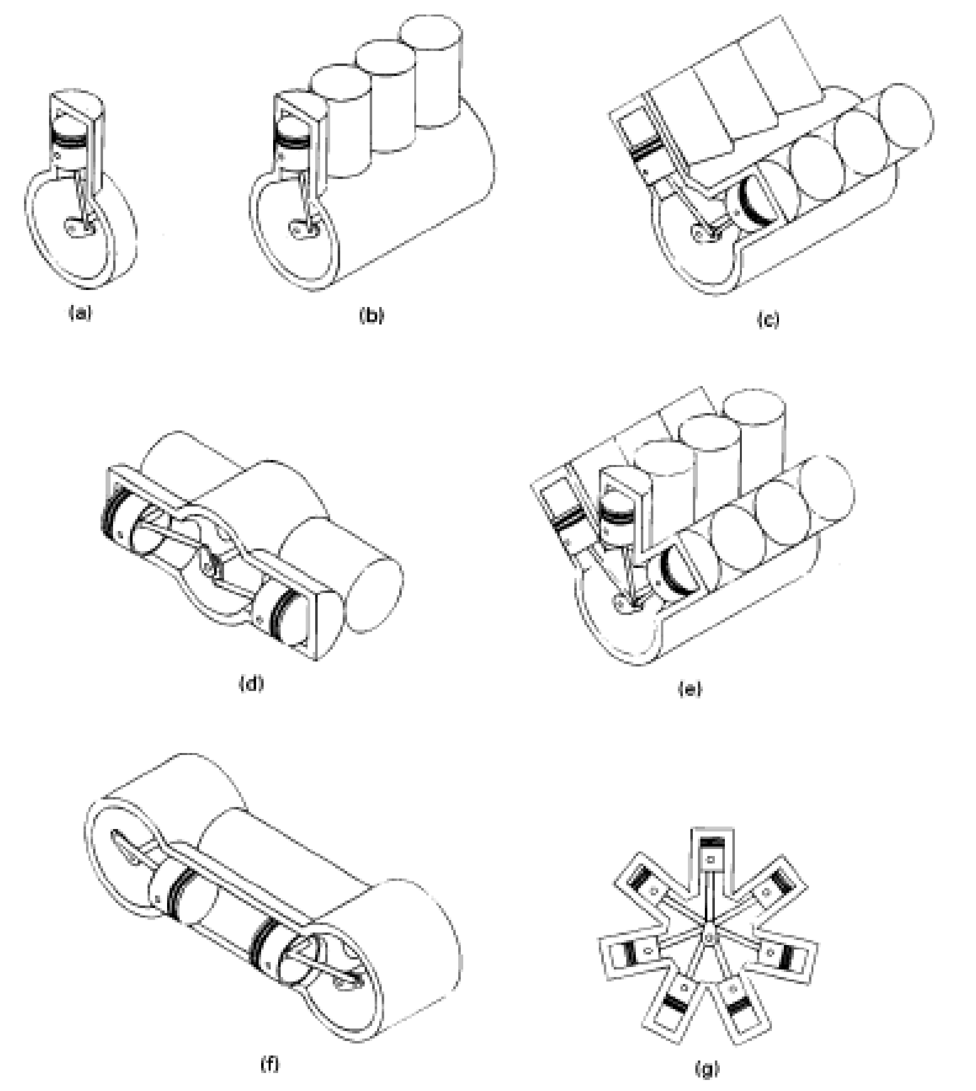
Internal combustion engines can be classified in a number of different ways:

Comparison of Four-stroke and two-stroke engine:

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

ENGINE CLASSIFICATIONS

3. Position and Number of Cylinders



Engine Classification by Cylinder Arrangement. **(a)** Single cylinder. **(b)** In-line, or straight. **(c)** V engine. **(d)** Opposed cylinder. **(e)** W engine. **(f)** Opposed piston. **(g)** Radial.

ENGINE CLASSIFICATIONS

Internal combustion engines can be classified in a number of different ways:

Other types of classifications

- **According to the type of fuel used-** (a) Petrol engine, (b) diesel engine, (c) gas engine (CNG, LPG, biogas), (d) Alcohol engine (ethanol, methanol etc) and more..
- **According to the working cycle-** (a) Otto cycle (constant volume cycle) engine, (b) diesel cycle (constant pressure cycle) engine, (c) dual combustion cycle (semi-diesel cycle) engine, (d) Atkinson (For Complete Expansion SI Engine), (e) Miller (For Early or Late Inlet Valve Closing type SI Engine)
- **According to the fuel supply and mixture preparation-** (a) Carburetted type (fuel supplied through the carburettor), (b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition - Port injection, Direct injection, GDI (Gasoline Direct Injection)).

ENGINE CLASSIFICATIONS

- **Method of cooling-** water cooled or air cooled
- **Speed of the engine-** Slow speed, medium speed and high speed engine
- **Valve or port design and location-** Overhead (I head), side valve (L head); in two-stroke engines: cross scavenging, loop scavenging, uniflow scavenging.
- **Application-** Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators.

TERMINOLOGY AND ABBREVIATIONS

The following terms and abbreviations are commonly used in engine technology literature and will be used throughout this course. These should be learned to assure maximum understanding of the following chapters.

Internal Combustion (ICE)

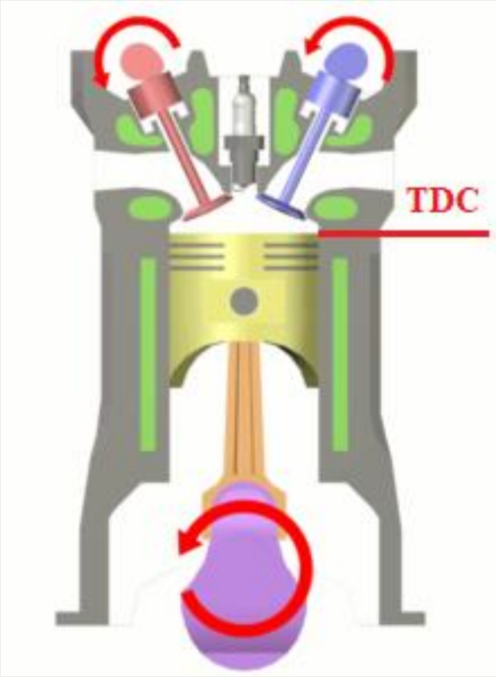
Spark Ignition (SI) An engine in which the combustion process in each cycle is started by use of a **spark plug**.

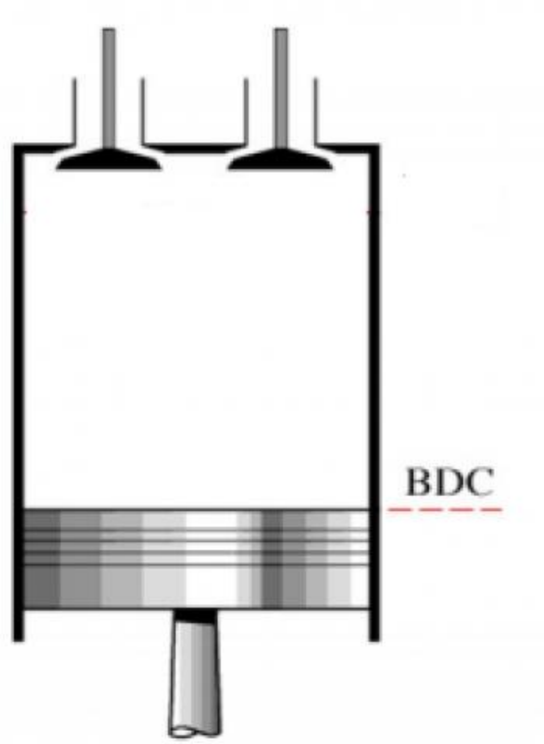
Compression Ignition (CI) An engine in which the combustion process starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression. CI engines are often called **Diesel engines**, especially in the non-technical community.

TERMINOLOGY AND ABBREVIATIONS

Top-Dead-Center (TDC)

Position of the piston when it stops at the furthest point away from the crankshaft. Top because this position is at the top of most engines (not always), and dead because the piston stops at this point. When the piston is at TDC, the volume in the cylinder is a minimum called the **clearance volume**.





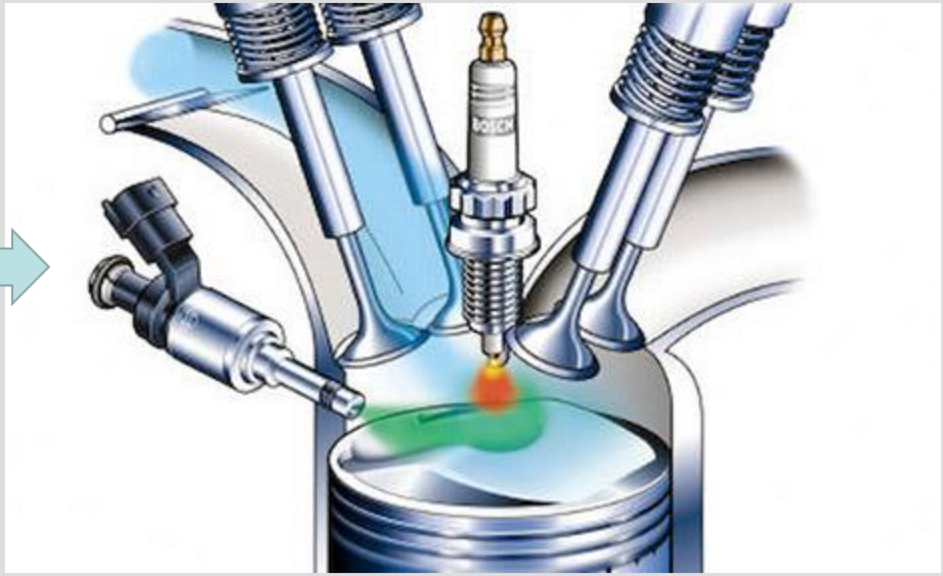
Bottom-Dead-Center (BDC)

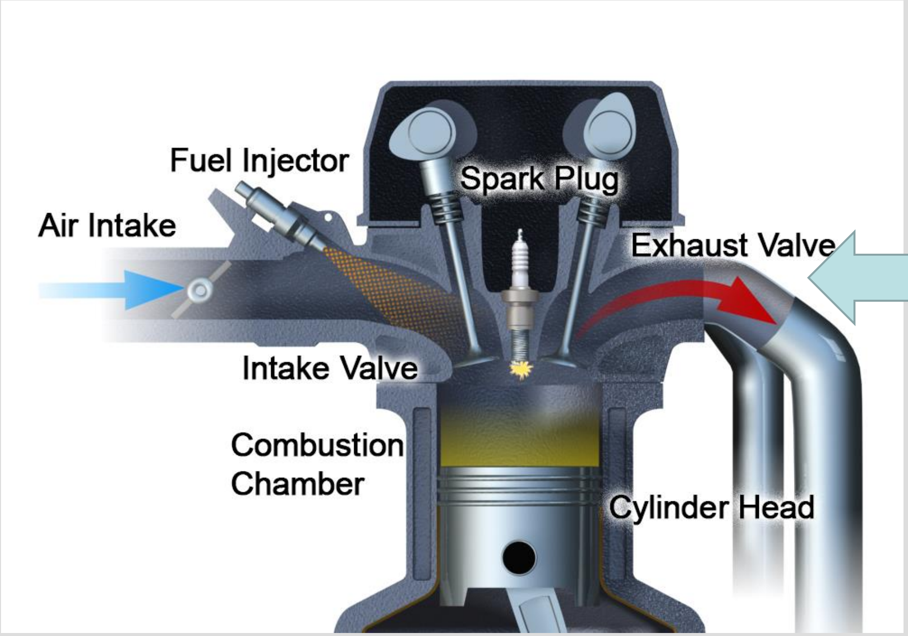
Position of the piston when it stops at the point closest to the crankshaft. Some sources call this Crank-End-Dead-Center (CEDC) because it is not always at the bottom of the engine. Some sources call this point Bottom-Center (BC). When the piston is at BDC, the volume in the cylinder is maximum.

TERMINOLOGY AND ABBREVIATIONS

Direct Injection (DI)

Fuel injection into the main combustion chamber of an engine. Engines have either one main combustion chamber (open chamber) or a divided combustion chamber made up of a main chamber and a smaller connected secondary chamber.





Port Injection (IDI)

Fuel injection into the secondary chamber of an engine with a divided combustion chamber. The most widely produced internal combustion engines were of the Port Fuel Injected (PFI) design, where the fuel is sprayed into the intake ports to mix with incoming air.

TERMINOLOGY AND ABBREVIATIONS

Bore Diameter of the cylinder or diameter of the piston face

Stroke Movement distance of the piston from one extreme position to the other: TDC to BDC or BDC to TDC.

Clearance Volume Minimum volume in the combustion chamber with piston at TDC.

Displacement or Displacement Volume Volume displaced by the piston as it travels through one stroke. Displacement can be given for one cylinder or for the entire engine (one cylinder times number of cylinders). Some literature calls this **swept volume**.

Air-Fuel Ratio (AF) Ratio of mass of air to mass of fuel input into engine.

Fuel-Air Ratio (FA) Ratio of mass of fuel to mass of air input into engine.

Brake Maximum Torque (BMT) Speed at which maximum torque occurs.

Overhead Valve (ORV) Valves mounted in engine head.

Overhead Cam (aRC) Camshaft mounted in engine head, giving more direct control of valves which are also mounted in engine head.

MAIN ENGINE COMPONENTS

Engine block: Body of engine

Piston: Reciprocates inside the cylinder and transfers power to crankshaft through connecting rod

Cylinder: Volume inside which the combustion takes place

Cylinder head: Top portion of engine cylinder which holds spark plugs, valves etc.

Crankshaft: Engine output is obtained

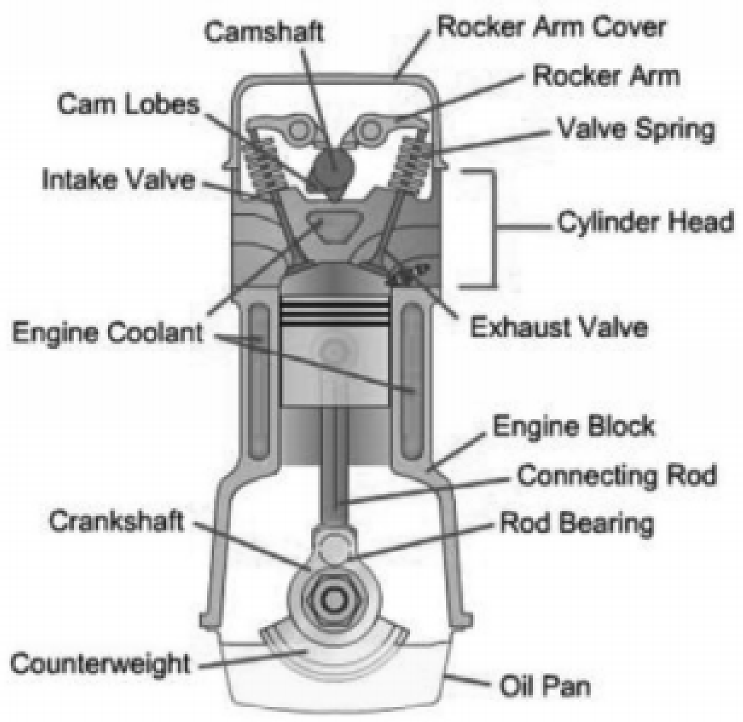
Connecting rod: Connects piston to crankshaft

Camshaft: Controls opening and closing of valves

Crankcase: Lower part of engine surrounding the crankshaft.

Intake valve: Allows air-fuel mixture to come in through intake manifold

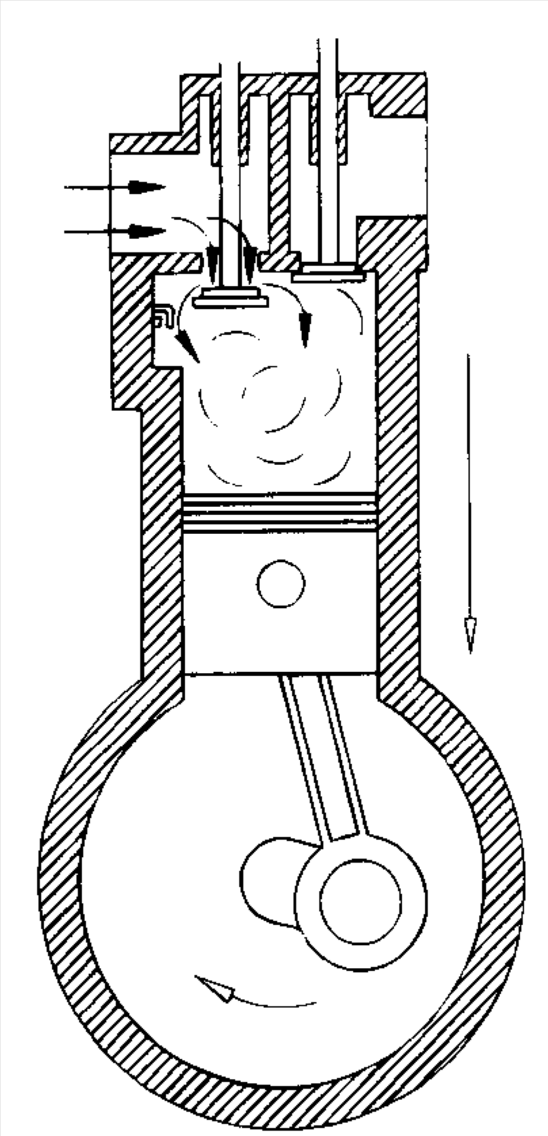
Exhaust valve: Allows burnt gases discharge through exhaust manifold



Basic components of an IC engine

BASIC ENGINE CYCLES

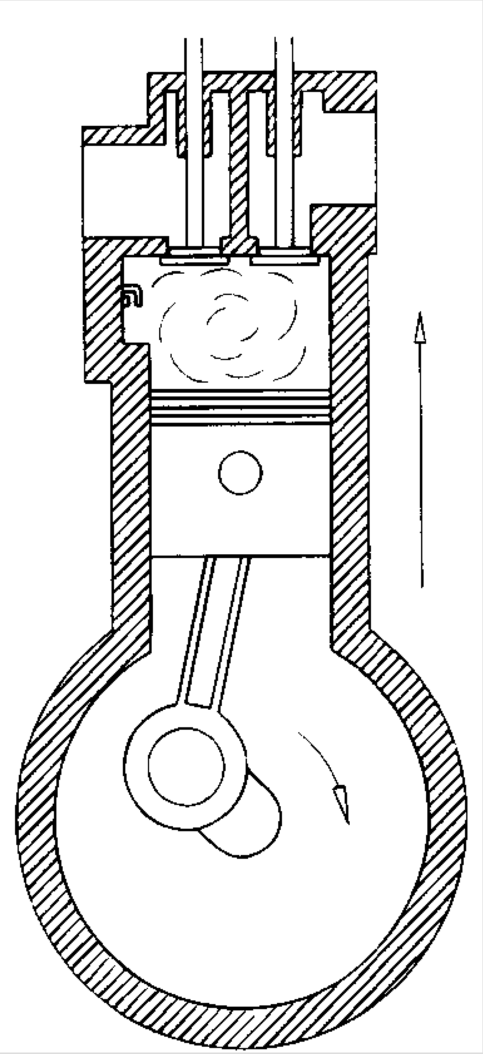
Four Stroke SI and CI Engine Cycles



Four-Stroke SI Engine Cycle

1. First Stroke: Intake Stroke or Induction

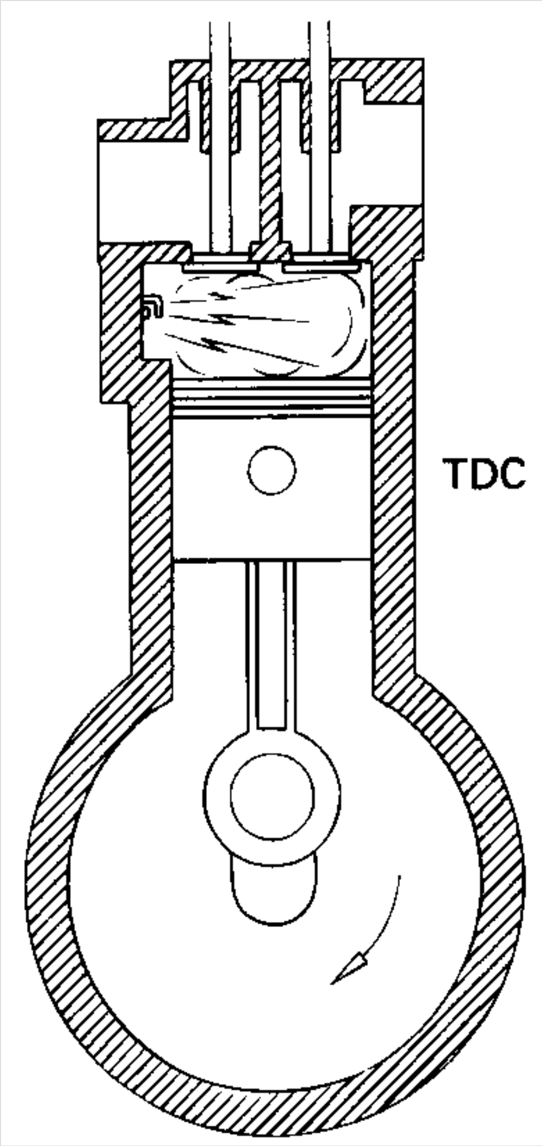
The piston travels from TDC to BDC with the intake valve open and exhaust valve closed. This creates an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure differential through the intake system from atmospheric pressure on the outside to the vacuum on the inside causes air to be pushed into the cylinder. As the air passes through the intake system, fuel is added to it in the desired amount by means of fuel injectors or a carburetor.



2. Second Stroke: Compression Stroke

When the piston reaches BDC, the intake valve closes and the piston travels back to TDC with all valves closed. This compresses the air-fuel mixture, raising both the pressure and temperature in the cylinder. The finite time required to close the intake valve means that actual compression doesn't start until sometime aBDC. Near the end of the compression stroke, the spark plug is fired and combustion is initiated.

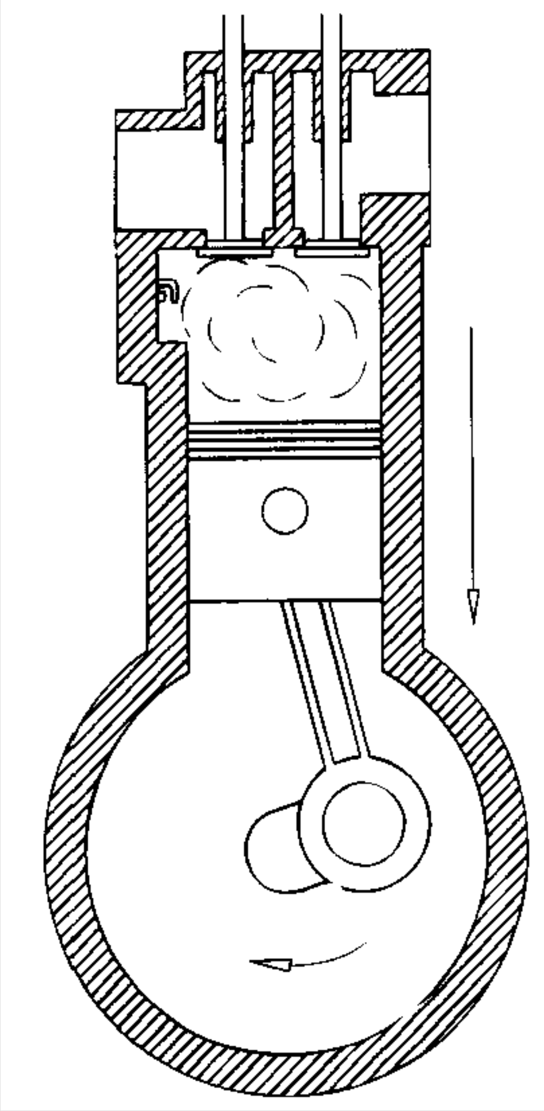
Four-Stroke SI Engine Cycle



3. Combustion

Combustion of the air-fuel mixture occurs in a very short but finite length of time with the piston near TDC (i.e., nearly constant-volume combustion). It starts near the end of the compression stroke slightly bTDC and lasts into the power stroke slightly aTDC. Combustion changes the composition of the gas mixture to that of exhaust products and increases the temperature in the cylinder to a very high peak value. This, in turn, raises the pressure in the cylinder to a very high peak value.

Four-Stroke SI Engine Cycle

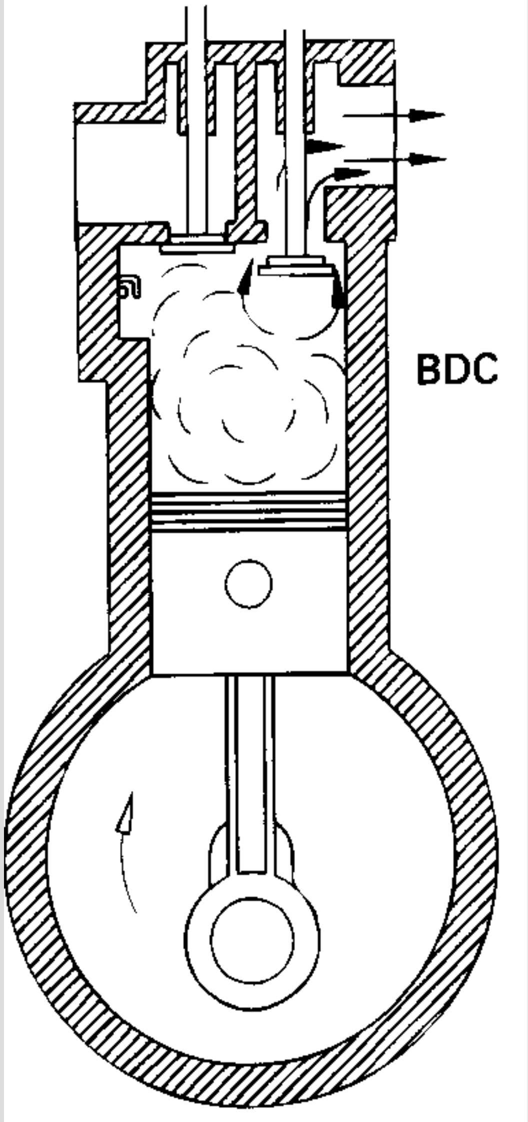


4. Third Stroke:

Expansion Stroke or Power Stroke With all valves closed, the high pressure created by the combustion process pushes the piston away from TDC. This is the stroke which produces the work output of the engine cycle. As the piston travels from TDC to BDC, cylinder volume is increased, causing pressure and temperature to drop.

Four-Stroke SI Engine Cycle

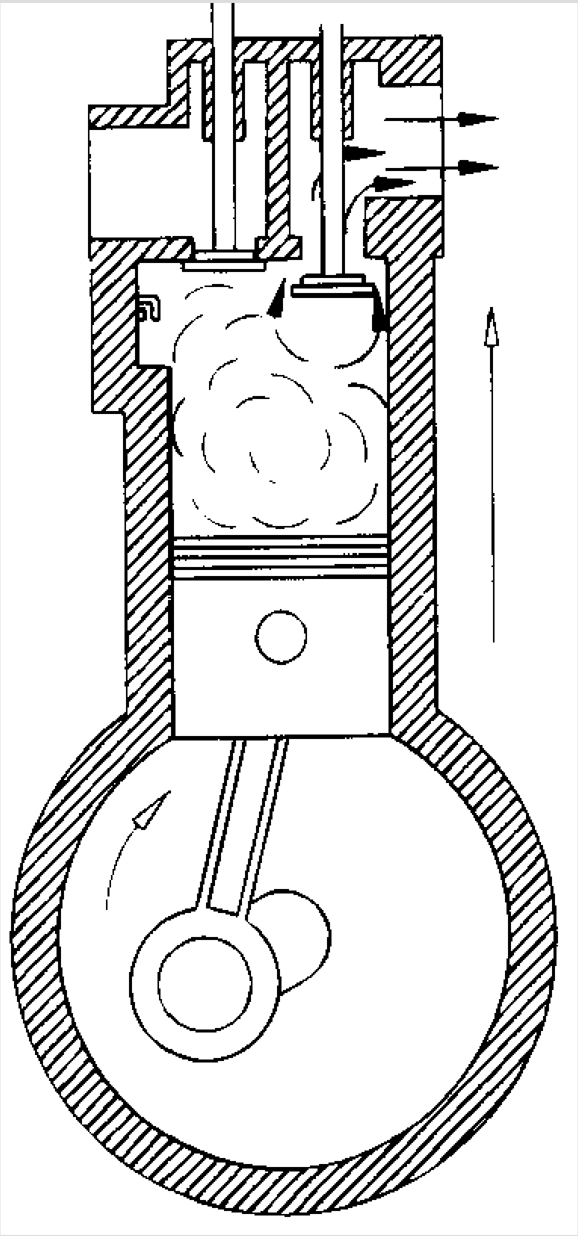
BASIC ENGINE CYCLES



5. Exhaust Blowdown

Late in the power stroke, the exhaust valve is opened and exhaust blow down occurs. Pressure and temperature in the cylinder are still high relative to the surroundings at this point, and a pressure differential is created through the exhaust system which is open to atmospheric pressure. This pressure differential causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system when the piston is near BDC. This exhaust gas carries away a high amount of enthalpy, which lowers the cycle thermal efficiency. Opening the exhaust valve before BDC reduces the work obtained during the power stroke but is required because of the finite time needed for exhaust blowdown.

Four-Stroke SI Engine Cycle



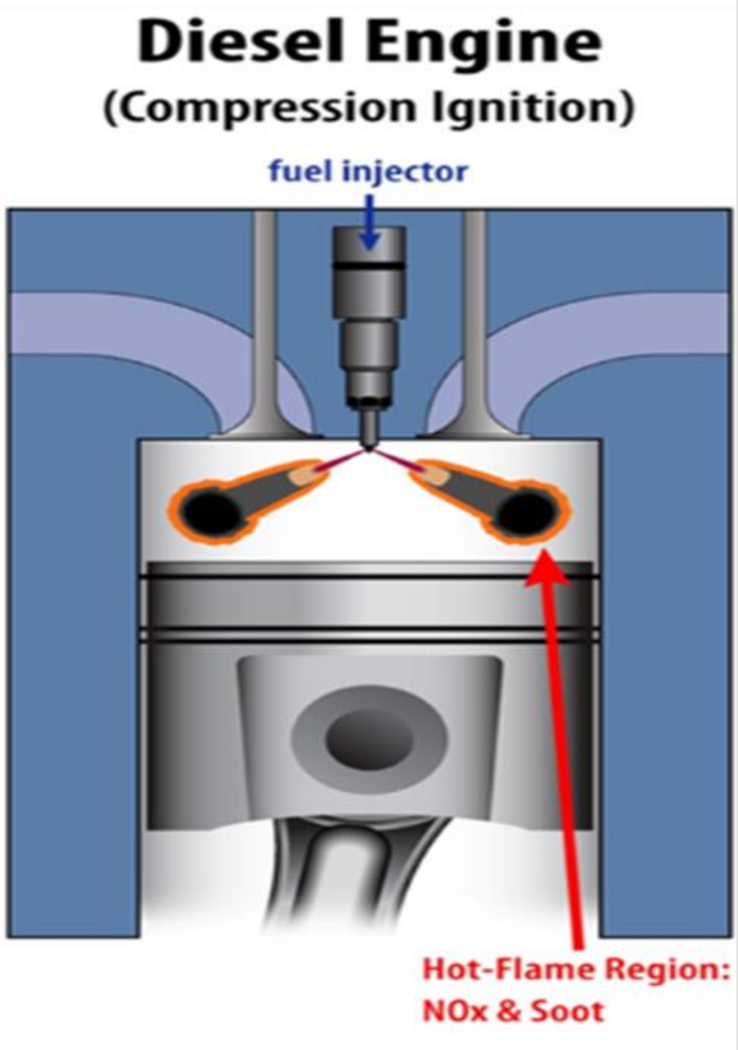
6. Fourth Stroke:

Exhaust Stroke By the time the piston reaches BDC, exhaust blowdown is complete, but the cylinder is still full of exhaust gases at approximately atmospheric pressure. With the exhaust valve remaining open, the piston now travels from BDC to TDC in the exhaust stroke. This pushes most of the remaining exhaust gases out of the cylinder into the exhaust system at about atmospheric pressure, leaving only that trapped in the clearance volume when the piston reaches TDC. Near the end of the exhaust stroke bTDC, the intake valve starts to open, so that it is fully open by TDC when the new intake stroke starts the next cycle. Near TDC the exhaust valve starts to close and finally is fully closed sometime aTDC. This period when both the intake valve and exhaust valve are open is **called valve overlap**.

Four-Stroke SI Engine Cycle

BASIC ENGINE CYCLES

Four Stroke SI and CI Engine Cycles



1. First Stroke: Intake Stroke The same as the intake stroke in an SI engine with one major difference: **no fuel is added to the incoming air.**

2. Second Stroke: Compression Stroke The same as in an SI engine **except that only air is compressed and compression is to higher pressures and temperature.** Late in the compression stroke fuel is injected directly into the combustion chamber, where it mixes with the very hot air. This causes the fuel to evaporate and self-ignite, causing combustion to start.

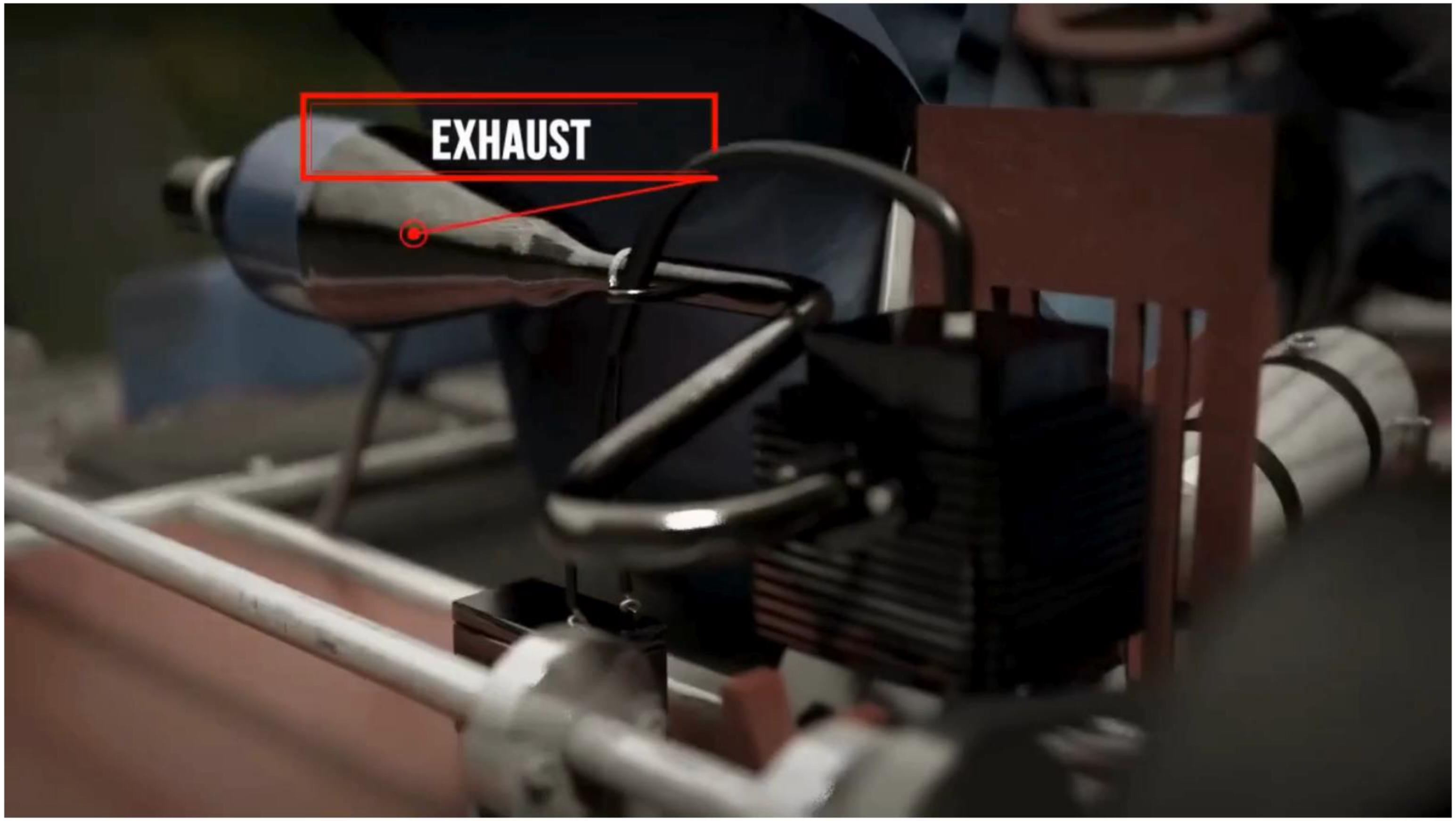
3. Combustion Combustion is fully developed by TDC and continues at about constant pressure until fuel injection is complete and the piston has started towards BDC.

4. Third Stroke: Power Stroke The power stroke continues as combustion ends and the piston travels towards BDC.

5. Exhaust Blowdown Same as with an SI engine.

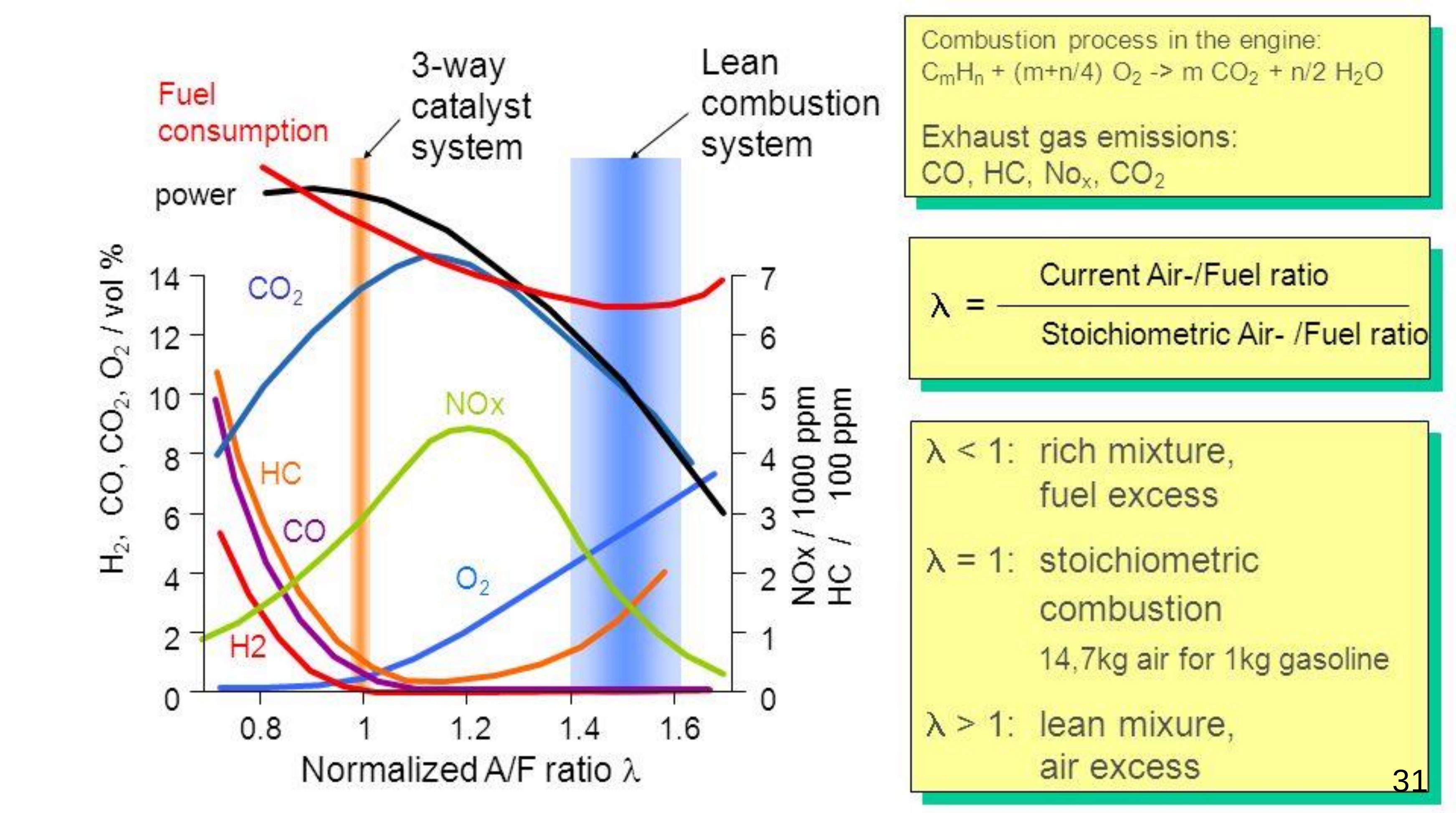
6. Fourth Stroke: Exhaust Stroke Same as with an SI engine.

Four-Stroke CI Engine Cycle


EXHAUST

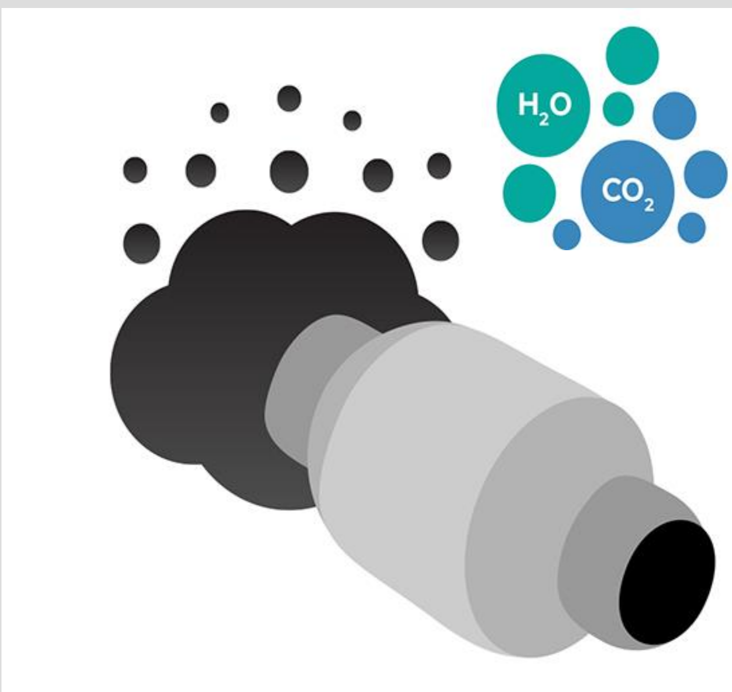
ENGINE EMISSIONS AND AIR POLLUTION

Four major *emissions produced by internal combustion engines are* ***hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and solid particulates.*** *Hydrocarbons are fuel molecules which did not get burned and smaller nonequilibrium particles of partially burned fuel.*

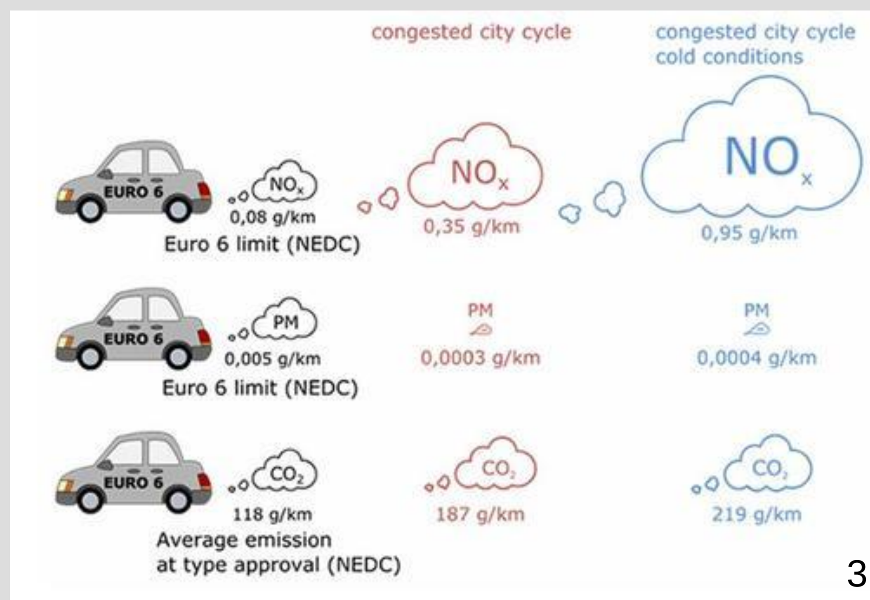


ENGINE EMISSIONS AND AIR POLLUTION

Carbon monoxide *occurs when not enough oxygen is present to fully react all carbon to* ***CO_2*** *or when incomplete air-fuel mixing occurs due to the very short engine cycle time. Oxides of nitrogen are created in an engine when high combustion temperatures cause some normally* ***stable N_2*** *to dissociate into* ***monatomic nitrogen N****, which then combines with reacting oxygen.* ***Solid particulates*** *are formed in compression ignition engines and are seen as black smoke in the exhaust of these engines. Other emissions found in the exhaust of engines include aldehydes, sulfur, lead, and phosphorus.*



Diesel Particulate



Summary

Homework-1 Questions

1. Current uses of External Combustion Engines
2. Definition of Atkinson Cycle and usage areas
3. Definition of Miller Cycle and usage areas
4. Definition of Valve overlap, types, and usage areas

First video:

https://www.youtube.com/watch?v=Z6YC3I54so4&t=31s&ab_channel=ThomasSchwenke

Second video:

https://www.youtube.com/watch?v=8dAbcbAJRw8&t=142s&ab_channel=TheEngineersPost