Chapter 3: Combustion

Oxygen + fuel = Combustion

Air has:
- 21% of O_2 & 79% N_2 by volume
- 23.3% of O_2 & 76.7% N_2 by mass

Fuels

Solid fuels
- Coal
- Anthracite
- Bituminous

Liquid fuels
- Hydrocarbons
  → Petroleum oils

These contain: C, H_2 & S

Gaseous fuel
- Natural gas
- Coal gas
- Producer gas
- Blast furnance gas

Combustion equation example:

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$2H_2$: 2 moles x (2 atoms x 1 Kg/Kmole) ; O_2: 1 mole x (2 atoms x 16 Kg/Kmole) ; $2H_2O$: 2 moles of water

4 Kg + 32 Kg = 36 Kg

- Mass flow is constant

Combustion with air:

$$2H_2 + O_2 + 3.76N_2 \longrightarrow 2H_2O + N_2$$

(3.76: volumetric percentage)

Complete & Incomplete Combustion

Combustion

Complete

- Fuels are completely burned
- Enough Oxygen available
- For hydrocarbons, No CO results

Incomplete

- Fuel is partially burned
- No enough Oxygen availa
- For hydrocarbons, CO results

Stochiometric or Chemically correct Air fuel ratio

Stochiometric → When there is sufficient oxygen for the complete combustion

Air fuel ratio → Lean/weak: Has excess air > Rich: Has Air deficiency

$$\% \text{ of excess air} = \frac{\text{Actual A/F ratio} - \text{Stochiometric A/F ratio}}{\text{Stochiometric A/F ratio}}$$

$$\varnothing \text{ (equivalent ratio)} = \frac{\text{Stochiometric A/F ratio}}{\text{Actual A/F ratio}}$$

Represents mixture strength

$\varnothing > 1$: Rich $\varnothing = 1$ Stochiometric

$\varnothing < 1$: lean

$$A/F = \frac{m_a}{m_f} = \frac{V_a}{V_f}$$

$\frac{V_a}{V_f}$ → Volumetric; number of moles in equation

Calorific value of fuel

- It is the quantity of heat generated when 1 Kg of liquid or Solid fuels is Completely burned
- It is the quantity of heat generated when 1 m^3 of gas fuels is Completely burned at N.T.P

NTP : Normal Temp & Pressure
=> 0°C & 760mm Hg

STP: Standard Temp & Pressure
=> 25°C & 760mm Hg

* Higher & lower calorific value

L.C.V : It is the quantity of heat generated when fuel is burned while water formed is in vapor form

H.C.V : It is the quantity of heat generated when fuel is burned while water formed is in condensed form

$$H.C.V = L.C.V + (m_s + 9H_2)\, 2240 \text{ KJ/Kg}$$

m_s → mass of moisture / Kg fuel

H_2 → composition percentage

2240 → latent heat of steam

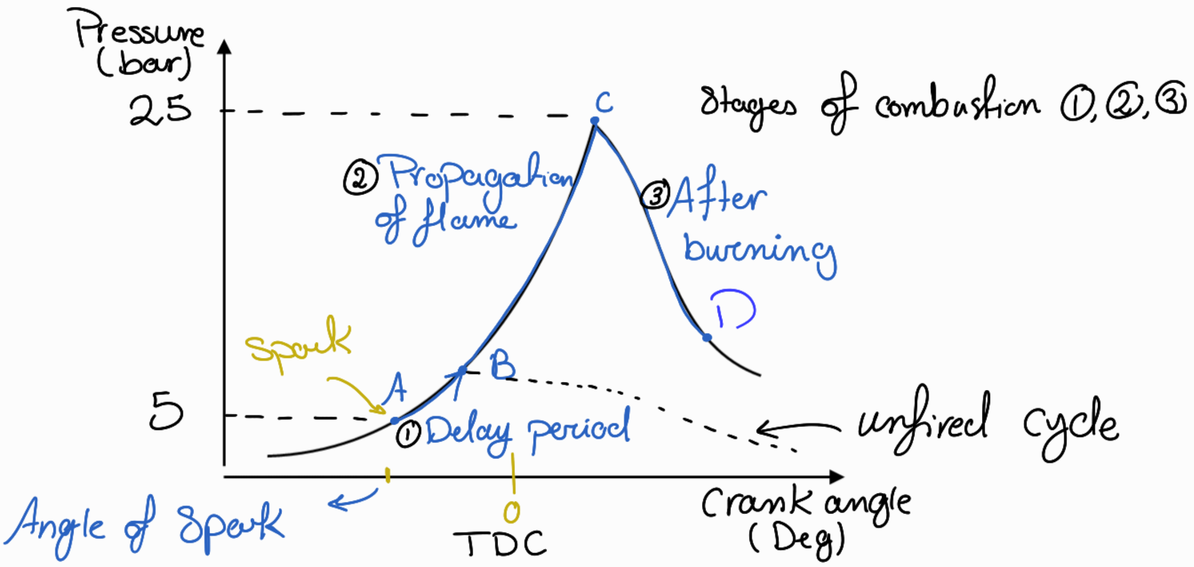
H.C.V of a composite
= % of element 1 x H.C.V of element 1
+ % of element 2 x H.C.V of element 2

Self ignition Temperature

- Min Temperature at which fuel burns when at contact with air
- Highest for Petrol / Kerosine is not used in ICE because SIT is low so r_v is low which means η is low

Combustion in Spark ignition engine

1. Normal combustion



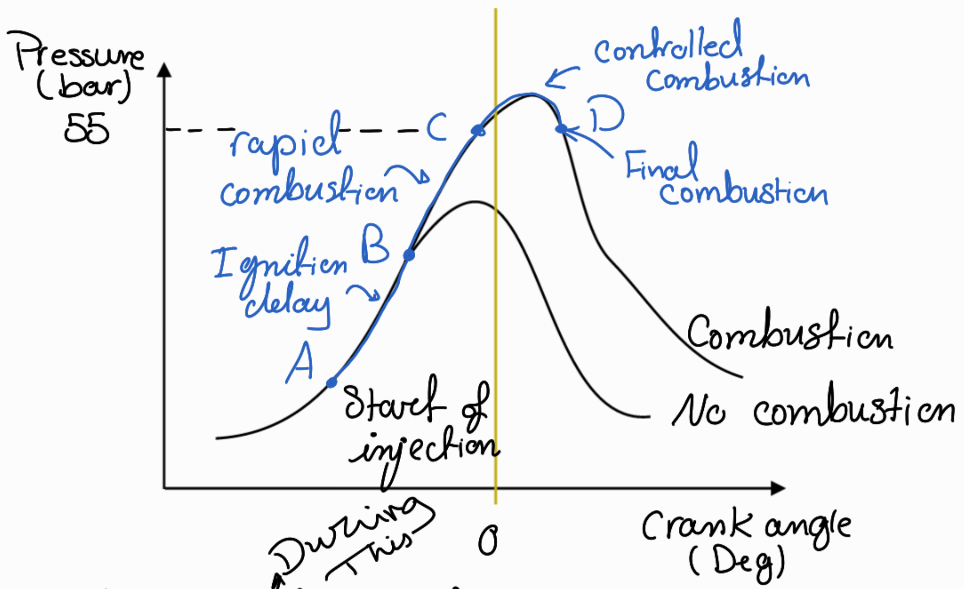
- Delay period occurs due to turbulenc (Does not change with Speed)
- Combustion starts after 5ms of spark
- Angle at which spark is given changes based on engine speed (proportional)
- Delay period depends on :
  1- Temperature
  2- Pressure
  3- A/F ratio
- Combustion occurs after TDC to have a smooth running engine with no sudden forc application

2. Abnormal Combustion

- Fuel/air mixture ignites with no ignition source (No Spark) due to contact with a hot surfac (s.a Exhaust valve)
- This combustion leads to Knocking → causes pre-ignition
  - High frequency vibration of combustion chamber content
- Knocking is caused by:
  1. Low quality fuel
  2. Deposits on Cylinder wall
  3. Wrong Spark plug

Go to Slide 24 & check factors

Combustion in compression ignition engine



1. Ignition delay AB: fuel is breaking up into droplets being vaporized (Due to ΔP from fuel system pressure to low)

- Pressure in fuel system can reach up to 3000 bar now

2. Rapid combustion / uncontrolled
- Rapid pressure increment
- Fuel/air mixture ignition

3. Controlled combustion
- Combustion occurs at a rate determined by the preparation of fresh air/fuel mixture

4. Final combustion
- End of combustion with all fuel or air is utilized

Pilot injection
- It is a system in which a small quantity of fuel is injected before main injection to prevent knocking

Characteristics of petrol

1. Volatility — Check slide 29 for definition

Gasoline is volatite at -20 °C, 1 bar

If Petrol is too volabile → vaporizes at high Temp → vapor lock فقعة غاز تمنع التدفق in fuel lines

If Petrol is not volabile enough → Engine is difficult to start (at low Temp) + affects fuel economy since not all fuel burns

2. Octane number
↳ chemical substance

- Measure of anti-knock preformance
- 0-100 Scale ⇒ 0 is for n-heptane : not anti knock
  100 is for iso-octane: a fuel resistant to knock
- 95 octane fuel equivalent to 95% iso octane & 5% of n-heptane (by volume) → improved by adding lead additive
- Chosen based:
  - Compression ratio : C.R=7.5 → 85 octane number
    C.R=10 → 100 octane number
  - Geometrical considerations
  - mechanical considerations
  - operating conditions

Characteristics of Diesel

→ Note: flash point is higher than Petrol or Kerosene → safer to store (flash point is at least 55°C)

1. Cetane number : indication of diesel oil
   - Scale of 0-100
     poor self ignition ← → good self ignition
   - A 60 cetane fuel would have ignition delay preformance equivalent to blend of 60% n-cetane and 40% α methyl nephthalene
   - Low cetane number causes Diesel knock → Too rapid combustion due to long ignition delay period
   - Ignition accelerators are used to improve cetane number (Back to slide 34) → nitrate

Flash point: The lowest temperature at which a liquid will form a vapor on the surface enough to from an ignitable mixture with air

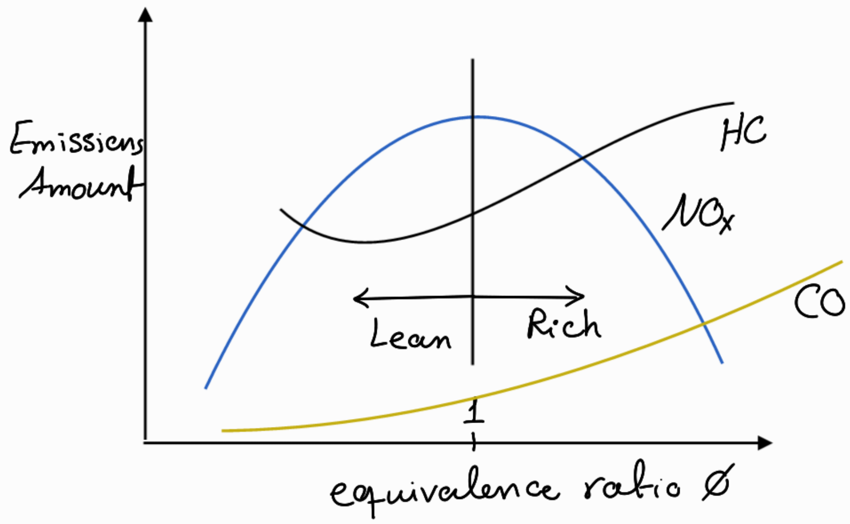
Engine Emissions

- Carbon monoxide CO : present due to dissociation process / increases with rich mixtures
- Various Oxides of nitrogen Nox } reacts in sunlight to cause photochemical smog → pollution
- Unburned hydrocarbones HC

* Petrol engines has higher emmisions than diesel engine due to rich mixtures

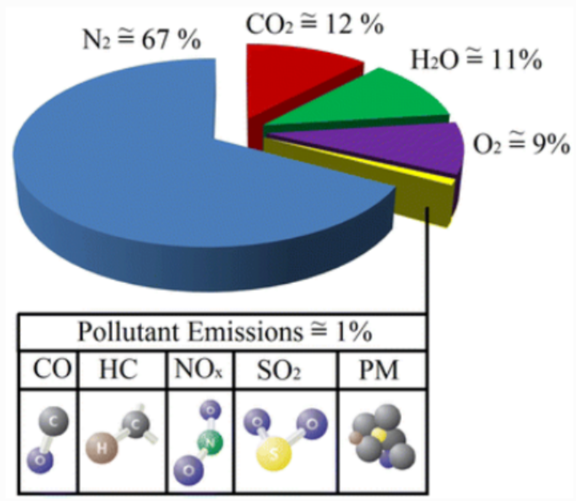
Diesel engine → produces black smoke or Soot → Diesel particulate filter is used to reduce it

Example of emissions in SI engine



To reduce :
- injection timing
- EGR → for NOx
- Advanced combustion

Emissions in CI engine



Seen & smell → Particulate matter is higher in diesel engine

CO, NO_x, HC is higher in gasoline

S. NO.	Spark Ignition Engines (SI)	Compression Ignition Engines (CI)
1	It draws air fuel mixture into the cylinder during suction stroke	It draws only air into the cylinder during suction stroke.
2	Petrol engines operate with low pressure and temperature	Diesel engines operate with high pressure and temperature
3.	Pressure ranges from 6 to 12 bar Temperature ranges from 250°C to 300°C	Pressure ranges from 35 to 40 bar Temperature ranges from 600oC to 700oC
4	It is fitted with carburettor and spark plugs	It is fitted with fuel injection pump and injectors
5	The burning of fuel takes place at constant volume	The burning of fuel takes place at constant pressure
6.	Ignition of air fuel mixture takes place by an electric spark produced by spark plug	Ignition of air fuel takes placed by a injection of fuel into the hot compressed air.

less maintenance cost

less noise

Proper Air fuel mixing

Factor	S.I. Engine	C.I. Engine
Intake/compression	Air and fuel	Air only
Ignition method	Spark plug	Compressed air and fuel
Speed control	Nearly homogeneous	Very heterogeneous
Mixture uniformity	Throttle air fuel mixture	Air un-throttled, fuel control only
Equivalence ratio	0.85 to 1.25	0 to 0.7
Exhaust temp.	Higher	Lower
Compression ratio range	7 to 14	15 to 21

No proper Air-fuel mixing

Quanlity Governed Quality Governed

SIE	CIE
Fuel is added to the air in the intake manifold system by fuel injectors	Fuel is added to the air in the cylinder by fuel injectors
Has spark plug	Does not have spark plug (But it has glow plug for the engine cold start)
Pressure in the system is 5 bar maximum	Pressure in the system can reach 3000 bar
Mixture at the beginning of combustion is rich	Mixture at the beginning of combustion is lean
Lead additives are added to gasoline to improve octane number	Ignition accelerators are added to diesel to improve cetane number (nitrate)
Higher emissions rate due to rich mixture	Lower emissions rate due to lean mixture
8<Compression ratio<14	12<Compression ratio<18
12<A/F<16	18<A/F<50
Air quantity can be controlled	Air quantity cannot be controlled
Overlap period is larger	Overlap period is smaller

For Solving Questions:

$$\% \text{ of excess air} = \frac{\text{Actual A/F ratio} - \text{Stochiometric A/F ratio}}{\text{Stochiometric A/F ratio}}$$

$$\text{Air moles} = \frac{\% \text{excess}}{100} \times \underset{\text{Number of moles}}{\text{Stochiom}} \times (O_2 + 3.76 N_2)$$

$$\varnothing \text{ (equivalent ratio)} = \frac{\text{Stochiometric A/F ratio}}{\text{Actual A/F ratio}}$$

When exhausts composition is given:

From C moles → Find H moles → Find O moles →
Find N moles

Efficiencies:

$$\eta_{volumetric} = \frac{V_{actual}}{V_{Theoretical}}$$

V_{actual} → $P\dot{V} = \dot{m}_a RT$

$V_{Theoretical}$ → Displacement Volume $= \left(\frac{\pi}{4} D^2 L\right) N n$

N → Number of cylinders

n → RPM of engine → Divide by 2 for 4 stroke engine

$$\eta_{Brake\ fuel\ conversion} = \frac{\text{Brake Power}}{\dot{m}_f Q_{HV}}$$

$$\eta_{mech} = \frac{\text{Brake Power}}{\text{Indicated Power}}$$

η_{comb} = percentage of burned fuel

$$1 - \eta_{comb} = \frac{\text{Exhaust chemical energy} \; (\leftarrow P_E)}{\dot{m}_f \, Q_{H.V}}$$

$$P_{friction} = \text{Indicated} - \text{Brake}$$

$$\text{Exhaust sensible energy} = \dot{m} Q - (P_{friction} + P_{Brake} + P_{Heat} + P_E)$$

Note: A.I.T

Diesel → 340°C

Petrol → 500°C

- If we put diesel and petrol in an engine with no spark the compression ratio for petrol will be so much higher than for diesel
- we need material, higher cost, higher work needed in Exhaust stroke and compression stroke
- If we put diesel in a petrol engine, it will work but with poor preformance + Incomplete combustion
- If we put gasoline in a diesel engine, the r_r is not enough for combustion so no burning

For the best torque the minimum ignition advance (MBT) which is a compromise for the beginning of ignition before TDC;

- To get MBT (Best Torque), Pre-injection is used to compensate for losses in the ignition before TDC catalytic converter: exhaust emission control device that converts toxic gases into less toxic by catalyzing

Scavenging: process of replacing exhaust gas in ICE cylinder with fresh air fuel mexture

Inproper scavenging → less power
exhaust remain