POLLUTANT FORMATION

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Engine emissions

SI engine vehicles without emission control have three sources of emissions

Exhaust emissions	:	Almost all of 100% of NOx and CO, and 60% of HC are emitted through the engine exhaust or vehicle tailpipe
Crankcase emissions	:	About 20% of HC are emitted via crankcase blow by gases
Evaporative Emissions	:	Fuel evaporation from tank, fuel system, carburettor and permeation through fuel lines constitute another 20% of total HC

CI engines on the other hand release all of harmful emissions into atmosphere through its exhaust gases

Typical Exhaust Emission Concentrations

SI Engine (Gasoline fuelled)

Depending upon engine operating conditions without catalytic control engine out emissions range :

CO	:	0.2 to 5% by volume (v/v)
HC	:	300 to 6000 ppmc1*, v/v
NO_x	:	50 to 2000 ppm, v/v

*$ppmc_1$= parts per million as methane measured by Flame Ionization Analyzer/Detector(FIA or FID)

CO emissions are high under engine idling and full load operation when engine is operating on fuel rich mixtures. HC emissions are high under idling, during engine warm-up and light load operation, acceleration and deceleration. NOx are maximum under full engine load conditions.

CI (Diesel) Engines

Diesel engines usually operate with more than 30% excess air band the emissions are accordingly influenced.

CO	:	0.03 to 0.1 %, v/v
HC	:	20 to 500 $ppmc_1$
NO_x	:	100 -2000 ppm
PM	:	0.02 to 0.2 g/m^3 (0.2 to 0.5% of fuel consumption by mass)

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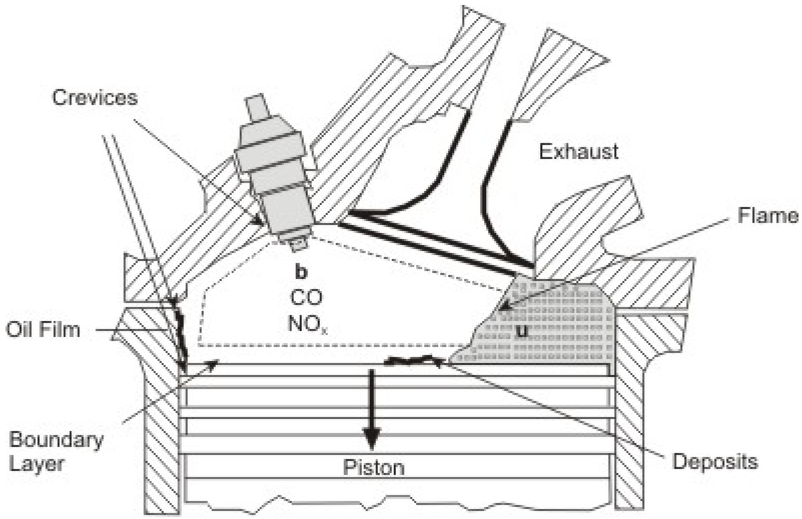
Emission Formation in SI Engines

Origin of SI engine exhaust emissions is shown schematically in Fig 2.1.



Figurer. 2.1	Schematic of progress of combustion in SI engine and pollutant formation

NO_x and CO are formed in the burned gases in the cylinder. Unburned HC emissions originate when fuel escapes combustion due to several processes such as flame quenching in narrow passages present in the combustion chamber and incomplete oxidation of fuel that is trapped or absorbed in oil film or deposits

- NO_x 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 NO_2 is also formed and NO and NO_2 together are called as NO_x.
- CO results from incomplete oxidation of fuel carbon when insufficient oxygen is available to completely oxidize the fuel. CO rises steeply as the air-fuel (A/F) ratio is decreased below the stoichiometric A/F ratio.
- HC originates from the fuel escaping combustion primarily due to flame quenching in crevices and on cold chamber walls, fuel vapour absorption in the oil layer on the cylinder and in combustion chamber deposits, and presence of liquid fuel in the cylinder during cold start

Air-fuel ratio is one of the most important parameter that affect the engine exhaust emissions. Typical variation in emissions with air-fuel ratio for premixed charge SI engines is shown in Fig. 2.2. The SI engine is operated close to stoichiometric air-fuel ratio as it provides a smooth engine operation. Nitric oxide emissions are maximum at slightly (5-10 %) leaner than stoichiometric mixture due to combination of availability of excess oxygen and high combustion temperatures at this point. Carbon monoxide and HC emissions reduce with increase in the air-fuel ratio as more oxygen gets available for combustion. Lean engine operation to a certain critical value of air-fuel ratio tend to reduce all the three pollutants. Further leaning of mixture results in poor quality of combustion and eventually in engine misfiring causing an erratic engine operation and sharp increase in HC emissions. Normally, one would like to operate engine on lean mixtures that would give low CO and HC, and moderate NO_x emissions. But, presently most engines are operated very close to stoichiometric conditions for catalytic control of

NO_X emissions,

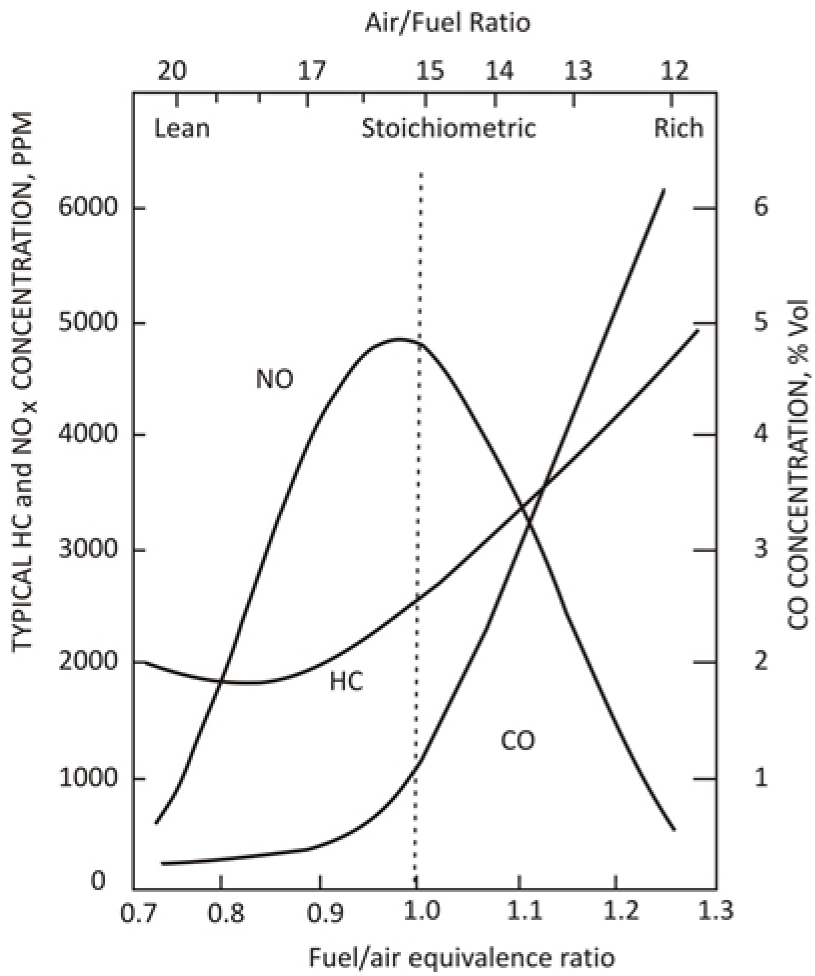


Figure 2.2	Variation in CO, HC and NO_X emissions for a SI engine

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Emission Formation in CI Engines

Schematic of a diesel injection spray is shown in Fig 2.3 . A fully developed diesel spray may be considered to consist of three distinct regions based on the variations in fuel-air equivalence ratio, ϕ across the cross section of the spray as seen radially outwards from the centreline of spray.

- A fuel rich core where fuel-air equivalence ratio is richer than the rich flammability limits i.e., $\phi > \phi_R$
- Flammable region in which ϕ lies within the rich and lean flammability limits, i.e., $\phi_R > \phi > \phi_L$
- A lean flame-out region (LFOR) where ϕ is lower than lean flammability limits and extends up to the spray boundary i.e., $\phi_L > \phi > 0$

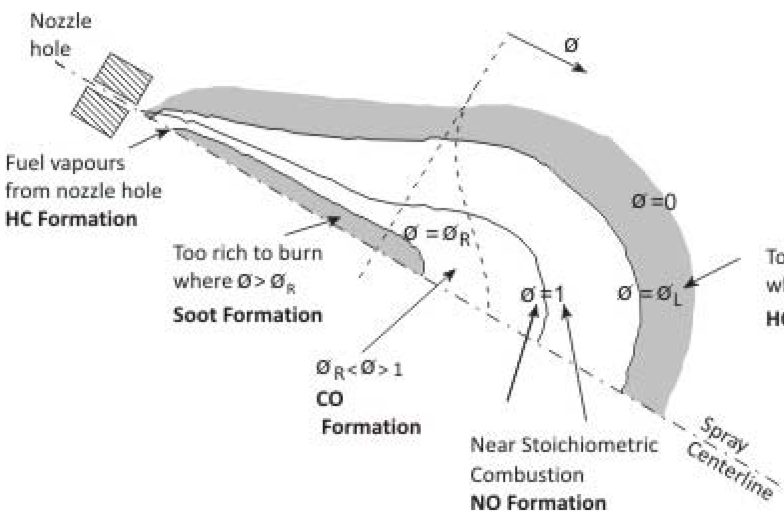

Figure. 2.3	Schematic representation of diesel spray, combustion and pollutant formation for a direct injection diesel engine

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Pollutant formation is strongly dependent on the fuel-air ratio distribution in the spray:

- NO is formed in the high temperature burned gases in the flammable region. Maximum burned gas temperatures result close to stoichiometric air-fuel ratio and these contribute maximum to NO formation.
- CO is formed in fuel rich mixtures in the flammable region.
- Soot forms in fuel-rich spray core where fuel vapour is heated by the hot burned gases $\phi > \phi_R$.
- Unburned HC and oxygenated hydrocarbons like aldehydes originate in the region where due to excessive dilution with air the mixture is too lean at the spray boundaries. In excessive lean mixtures combustion process either fails to begin or does not reach completion. Towards the end of combustion, fuel in the nozzle sac and orifices gets vaporized, enters the combustion chamber and contributes to HC emissions.

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