

## Module 2:Genesis and Mechanism of Formation of Engine Emissions

### Lecture 9:Mechanisms of HC Formation in SI Engines.... contd.

#### Mechanisms of HC Formation in SI Engines.... contd.

The Lecture Contains:

- HC from Lubricating Oil Film
- Combustion Chamber Deposits HC
- Mixture Quality and In-Cylinder Liquid Fuel
- HC from Misfired Combustion

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### HC from Lubricating Oil Film

Fuel hydrocarbons are absorbed in the oil film present on the cylinder walls during intake and compression strokes, which get desorbed back into the burned gases during combustion and expansion. On combustion, the partial pressure of fuel in the burned gases becomes nearly zero and the concentration gradient makes the fuel to be desorbed from oil and diffuse back into the burned gases. The desorbed fuel vapours from oil film are oxidized depending upon the temperature, pressure and composition of the burned gases.

The maximum amount of fuel that can be dissolved per unit volume of oil is given by:

$$n_{fo} = n_o X_{fc} P / H \quad (2.33)$$

where,  $n_{fo}$  is the number of moles of fuel absorbed in oil,  $n_o$  is number of moles of oil per unit volume,  $X_{fc}$  mole fraction of fuel in the combustion chamber gases close to the oil film,  $P$  is instantaneous cylinder pressure,  $H$  is the Henry's constant. Mole fraction of fuel vapours in oil,

$$x_f = \frac{n_{fo}}{n_o + n_{fo}} \approx \frac{n_{fo}}{n_o} \quad (2.34)$$

$$\frac{n_{fo}}{n_o} \approx X_{fc} P / H$$

As  $n_{fo} \ll n_o$ ,  $x_f$  can be approximated as  $n_{fo} / n_o$ .

Henry's constant is a measure of fugacity of the fuel components (solute) in liquid phase or inverse of its solubility. Henry's constant increases with temperature and decreases exponentially with increase in molecular weight of the solute (in present case the fuel). At 400 K, Henry's constant for n-hexane, iso-octane and ethyl-benzene is 200, 120 and 45 kPa, respectively. A larger fraction of the heavier fuel components would be absorbed in the oil as they have a smaller value of  $H$ . Taking average cylinder pressure under compression stroke as 0.5 MPa and typical oil film temperature equal to 400 K, the mole fraction of fuel vapour absorbed in oil film at equilibrium for the stoichiometric mixture of isooctane and air would be about 0.07

The lubricant oil film thickness is a strong function of oil viscosity and hence the oil temperature. It also varies with engine speed. The oil film thickness on the cylinder wall varies between 1 and 10  $\mu\text{m}$ . At temperature of 400 K, the diffusion time to reach equilibrium for fuel vapour absorption in oil film of 1  $\mu\text{m}$  thickness is about  $10^{-3}$  seconds and for a 10  $\mu\text{m}$  thick film it would equal to  $10^{-1}$  seconds. For an engine speed of 3000 rpm, intake and compression strokes together would take  $2 \times 10^{-2}$  seconds. Thus, for oil films of 1 to 2  $\mu\text{m}$  thickness state of equilibrium in fuel vapour absorption would be achieved under engine conditions.

The absorption and desorption of fuel in the oil film and its contribution to the HC emissions involves several processes. Some of the absorbed hydrocarbon vapours in oil are carried to the crankcase where these are desorbed.

It has been seen that when lubricating oil was added to fuel or to the engine cylinder or deposited on the piston crown, the exhaust hydrocarbons increased in proportion to the oil added. The increased exhaust HC from the engine were identified as unburned fuel and partially oxidized fuel species and not the unburned oil or oil oxidation species.

Potential HC contribution of the engine oil film depends on the solubility of fuel in the engine oil and the amount of engine oil present in the combustion chamber.

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#### Combustion Chamber Deposits HC

Deposits are formed in the intake system, on the valves, combustion chamber and piston crown after engine operation for several thousand kilometres. The combustion chamber deposits are carbonaceous in composition and porous in nature. Olefins, aromatics and heavier fuels result in higher deposit build up. Engine operation for 50 to 100 hours under cyclic and variable load and speed conditions can result in deposit thickness of around 100 mm in the combustion chamber.

The fuel-air-residual gas charge is compressed into pores of deposits. As the pore size is smaller than the quench distance, the flame cannot penetrate into deposit pores. The unburned mixture comes out of pores during expansion and diffuses back into burned gases. Some of these hydrocarbons will burn up on mixing with the hot burned gases. But, as the temperatures drop on expansion a large fraction of these may fail to get oxidized and are emitted from the engine.

On the other hand, the deposits formed on the combustion chamber surface reduce heat transfer and it may decrease quench layer thickness. Prevention of heat transfer by the combustion chamber deposits increases charge temperatures and hence lower HC emissions. However, the overall effect of deposits is to increase HC emissions.

In the engine and vehicle tests, combustion chamber deposits are seen to increase HC emissions by 10 to 25 percent

#### Mixture Quality and In-Cylinder Liquid Fuel

Very rich fuel-air mixture has to be supplied during cold starting as fuel evaporation is poor at low engine temperatures. During acceleration, delayed dynamic response of the fuel system to meet the engine requirements again requires supply of overly rich-mixtures. The carburetted engines are to be supplied a richer fuel mixture than the modern PFI engines as there is a delay for the metered fuel in reaching the cylinder. Also, the carburettor is unable to precisely control the fuel quantity. The port fuel injection systems (PFI) i.e., separate fuel injectors for each cylinder provide more precise fuel metering and more uniform fuel distribution among cylinders. PFI also gives a better control of air-fuel ratio during cold starting and response to transient operation compared to the carburettor.

Fuel injection process in a PFI engine is shown schematically in (Fig 2.13). Mixture preparation is governed by factors such as:

- Fuel atomization and droplet size
- Fuel vaporization on the back of the intake valve depending upon its temperature, and
- Mixing with intake air and hot residual gases. The hot residual gases flow back into the intake manifold as the intake valve opens and its amount depends on the operating conditions. The injected fuel comes into contact with these hot residual gases that help fuel vaporization.

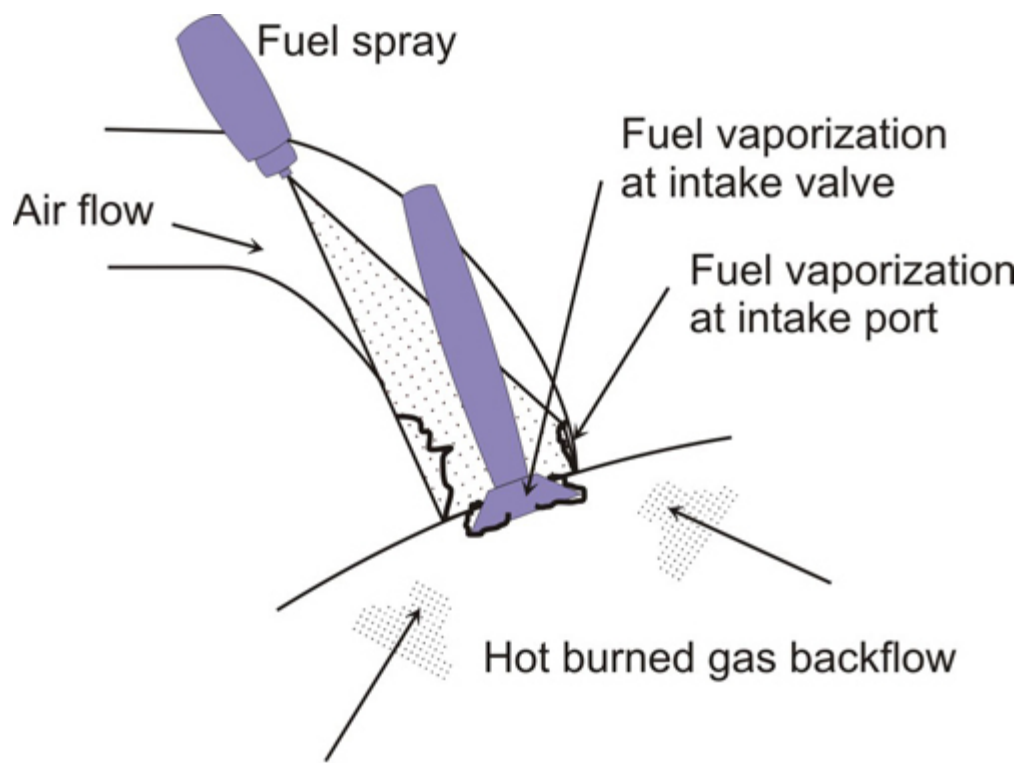


Figure 2.13

Schematic of Port Fuel Injection and fuel vaporization process

Some features of fuel induction into the cylinder of PFI engines are:

- The conventional PFI system produces the droplets of Sauter mean diameter (SMD) ranging from  $130\text{ }\mu\text{m}$  to  $300\text{ }\mu\text{m}$ . The droplets larger than  $10\text{ }\mu\text{m}$  are unable to follow the air stream and they impinge on the combustion chamber walls producing a non-uniform fuel distribution in the cylinder.
- As the injection is made at the back of intake valve, liquid fuel film is formed at the port and on the back of the valve. The intake air strips this liquid fuel film and carries along into the cylinder. In the process, substantial amount of liquid fuel droplets enter the engine cylinder and is deposited on cylinder walls.
- Shearing of the liquid film from the back of intake valve and port by intake air produces larger droplets than by the injectors which impinge on the cylinder walls depositing liquid fuel film.
- Injection at a higher pressure although would produce finer droplets but the fuel jet velocity and droplet momentum are also higher, which increases the probability of the impingement of the fuel droplets on walls.
- During cold start as 8 to 15 times of the stoichiometric fuel requirement is injected for the first few cycles, more liquid fuel is deposited inside the cylinder.

The liquid fuel deposition inside the cylinder decreases as the engine is warmed up. During cold starting and warm up, much of the injected fuel remains in the cylinder for several cycles. It vaporizes during and after combustion and thus, contributes to higher HC emissions. During cold start, with PFI up to 60% higher HC emissions could result compared to fully vaporized and premixed air and fuel mixture. At  $90^\circ\text{C}$  coolant temperature, the contribution of the liquid fuel deposited inside the cylinder to HC emissions is almost zero compared to 20 to 60 percent at  $20^\circ\text{C}$ .

In the modern catalyst equipped vehicles, more than 90 percent of HC emissions under standard test driving cycle conditions result during the first minute of operation. due to use of over-rich mixtures

during engine start-up and secondly the catalytic converter has not yet warmed up and is not functional.

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#### HC from Misfired Combustion

Engine may misfire under engine idling and low load operation as the residual gas dilution is high.

Presence of high residual gas content retards combustion and more fuel burns during expansion stroke. However, during expansion as the cylinder pressure falls the temperature of the unburned mixture ahead of the flame also decreases which may result in extinction of flame and consequently in partially misfired combustion. Such bulk flame quenching in spark-ignition engines leads to very high HC emissions. Use of excessively lean mixtures also decreases burning rates and increases incidence of bulk gas flame quenching. The propensity to partial misfiring increases under transient engine operation. Use of large amounts of exhaust gas recirculation (EGR) or high residual gas dilution though reduces NO formation but results in high HC emissions.

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