

1 a) Gasoline engines:

- 1) CO - Carbon monoxide
- 2) UHC - unburnt hydrocarbon
- 3) NO<sub>x</sub> - nitric & nitrogen dioxide.

Diesel engines:-

- 1) UHC
- 2) NO<sub>x</sub>
- 3) PM. - Particulate matters (soot, etc)

Origin of the pollutants in gasoline engine:-

- 1) CO:- - Fuel rich operation.  
- insufficient oxygen to convert all C into CO<sub>2</sub>.  
- Cold startup - (warm up) condition.

2) UHC:-

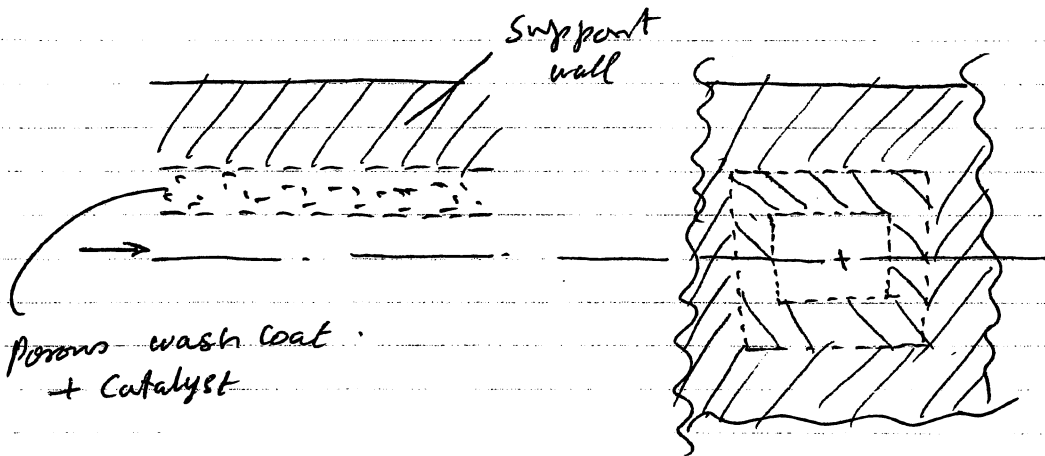
- i) Crevices - cavity in the engine head & around the piston - unburnt fuel in these cavities escapes in the normal combustion process.
- ii) oil layers
- iii) Deposits: - Carbon build up over period.
- (iv) Flame quenching/poor combustion.
- (v) Exhaust valve leakage.

3) NO<sub>x</sub>:-

- Thermal NO<sub>x</sub>
- Fuel bound N<sub>2</sub>
- Prompt NO<sub>x</sub>
- Nitrous oxide N<sub>2</sub>O

The predominant mechanism is thermal NO<sub>x</sub>.

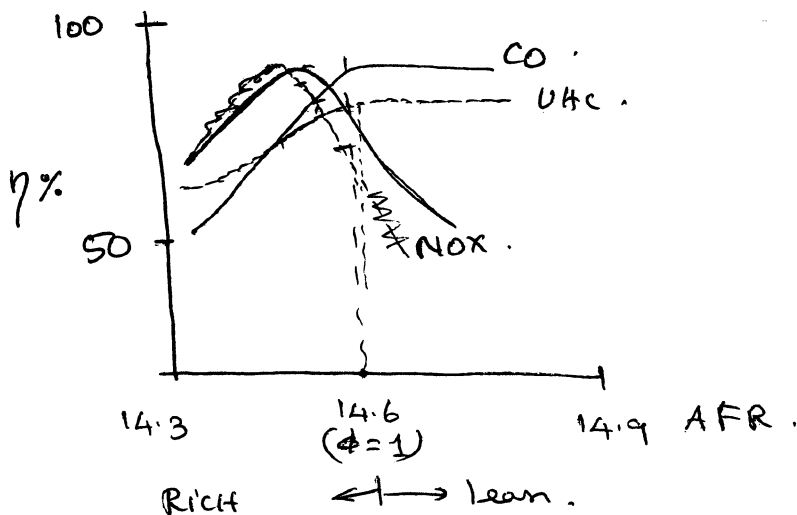
b)



- Support wall:-
- mechanical support
  - light weight, - Ceramic, Cordierite
  - Almost zero thermal expansion.
  - 0.1 to 0.2 mm thickness.

- Wash coat:-  $\gamma\text{Al}_2\text{O}_3$  (gamma Aluminium oxide)
- increases the surface area per unit volume by 500X
  - Cerium oxide is added to wash coat to increase its thermal stability
  - Also acts as oxygen storage during lean operation of the engine.

- Catalyst:-
- promote chemical reactions at low T via additional chemical pathways.
  - Pt, Pd, Rh are used
  - Pt & Pd - for CO & UHC removal
  - Rh - for NOX removal.

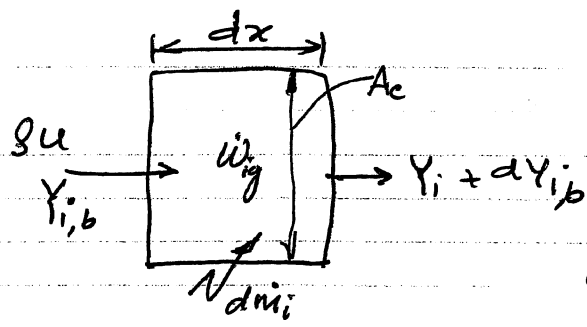


2) c) No. Three-way catalyst can't be used in diesel engines. ~~be~~ For their proper operation, the engine should run at stoichiometric condition. But in diesel engines, smoke emissions limits the equivalence ratio ( $\lambda$ /AFR) to be below ~~at~~ about 0.7.

$\Rightarrow$  The engine runs always lean. This is very conducive for CO & UHC oxidation. But not for  $NO_x$  reduction.

Thus the three-way catalyst can't be used in diesel engines.

2 a)



$$d\dot{m}_i = \rho h_{o,i} (Y_{i,s} - Y_{i,b})$$

Balance!

wetted perimeter

$$- \rho u dY_{i,b} A_c + \dot{w}_i A_c dx + d\dot{m}_i P dx = 0$$

$$- \rho u \frac{dY_{i,b}}{dx} + \dot{w}_i + \rho h_{o,i} (Y_{i,s} - Y_{i,b}) \left( \frac{P}{A_c} \right) = 0$$

$$\epsilon \rho u \frac{dY_{i,b}}{dx} + \epsilon \dot{w}_i + \rho h_{o,i} S (Y_{i,s} - Y_{i,b}) = 0$$

neglect the homogeneous reactions  $\Rightarrow \dot{w}_i \approx 0$ .

$$\Rightarrow \epsilon u \frac{dY_{i,b}}{dx} + h_{o,i} S (Y_{i,b} - Y_{i,s}) = 0$$

$$Y_{i,b} - \text{mass fraction} = \frac{m_i}{m} = \frac{\rho_i}{\rho} = \left( \frac{n_i}{n} \right) \left( \frac{M_i}{M} \right)$$

$$= Y_i \frac{M_i}{M} \Rightarrow Y_i = \left( Y_{i,b} \frac{M}{M_i} \right)$$

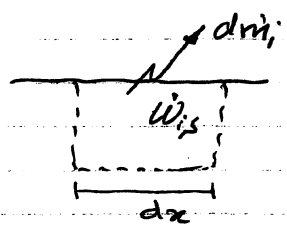
$$\Rightarrow \epsilon u \frac{dY_{i,b}}{dx} + h_{o,i} S (Y_{i,b} - Y_{i,s}) = 0$$

if  $M$ -average mixture molecular wt is const.

(or the variation of  $M$  along the cell is negligible or small)

This is valid in practice, because the exhaust gases from the engine contains predominantly  $N_2$ . Thus mixture properties are close to the property of  $N_2$ .

2 (b)



kg/m<sup>3</sup> of catalyst  
m<sup>2</sup>/m<sup>3</sup>

$$- d n_{i1} P dx = \dot{w}_{i1} a (A_T dx) \rightarrow m^3$$

kg/m<sup>2</sup> sec

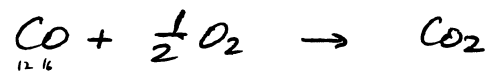
$$S k_{d1} (Y_{i1b} - Y_{i1s}) = \dot{w}_{i1} a \left( \frac{A_T}{P} \right)^{1/2}$$

$$\Rightarrow S k_{d1} (Y_{i1b} - Y_{i1s}) = a \dot{w}_{i1} = a \hat{R}_i M_i$$

$$\boxed{a \hat{R}_i = \frac{S k_{d1}}{M_i} (Y_{i1b} - Y_{i1s})}$$

2 (c)

$$a \hat{R}_i = \frac{S k_{d1}}{M_i} (Y_{i1b} - Y_{i1s})$$



$\Rightarrow (2 * 28) \text{ kg of CO for } 32 \text{ kg of } O_2$

$$\Rightarrow Y_{O_2,s} = \left( \frac{32}{56} \right) Y_{CO,s}$$

$$Y_{CO,s} = 1.75 Y_{O_2,s} ; \quad Y_{CO,s} = 2 \left( \frac{M_{CO}}{M_{O_2}} \right) Y_{O_2,s}$$

$$\hat{R}_{CO,s} = \frac{K_1 Y_{CO,s} Y_{O_2,s}}{G} = \frac{K_1 Y_{CO,s} \left( \frac{M}{M_{O_2}} \right) Y_{O_2,s} \left( \frac{M}{M_{O_2}} \right)}{G}$$

$$= \frac{K_1 (M^2 / M_{CO} M_{O_2})}{G} Y_{CO,s} Y_{O_2,s}$$

$$= \frac{K_1 (M^2)}{G (M_{CO} M_{O_2})} Y_{CO,s}^2 \frac{M_{O_2}}{2 M_{CO}}$$

$$= \frac{K_1 (M)}{2G (M_{CO})} Y_{CO,s}^2$$

$$G = T(1 + K_1 y_{CO} + \dots)^2 (\dots)$$

low concentrations (mol)  $\Rightarrow y_{CO} \& y_{O_2} \approx 0$ .

$$\Rightarrow G \approx T$$

$$\therefore \hat{R}_{CO,S} = \frac{k_1}{2T} \left(\frac{M}{M_{CO}}\right)^2 Y_{CO,S}^2$$

$$a \frac{k_1}{2T} \left(\frac{M}{M_{CO}}\right)^2 Y_{CO,S}^2 = \frac{p_{H_2O} S}{M_{CO}} (Y_{CO,b} - Y_{CO,S})$$

$$Y_{CO,S}^2 = \left(\frac{p_{H_2O} S M_{CO}}{k_1 a R M^2}\right) 2 (Y_{CO,b} - Y_{CO,S})$$

$$Y_{CO,S}^2 = 2\theta (Y_{CO,b} - Y_{CO,S})$$

$$\Rightarrow Y_{CO,S} = \theta \left(-1 + \sqrt{1 + \frac{2Y_{CO,b}}{\theta}}\right)$$

$$\frac{Y_{CO,S}}{\theta} = -1 + \sqrt{1 + \frac{2Y_{CO,b}}{\theta}}$$

Take two solutions  
-ve soln - no meaning.

3) a) PM - is not of major concern in present day gasoline engines. Sulphur content in the fuel is regulated & controlled. Lead (Pb) used to be a problem but not anymore because of the use of unleaded fuel.

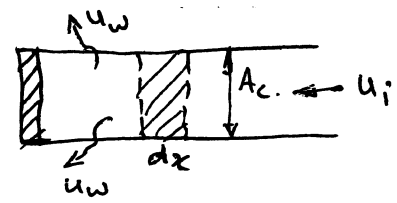
- The engine operates with homogeneous mixture  $\Rightarrow$  No Soot problem.

- For diesel engines, the particulate matter emission is one of major emissions. It can be controlled via the use of DPF, Diesel Particulate filter.

PM - Substance other than water, that can be collected by filtering the exhaust.

- Soot, or Solid Carbon,
- Condensed organic & inorganic compounds & their partial oxidation products.

b)



$$A_c d(\rho u_i) = -P dx \rho u_w \Rightarrow \boxed{\frac{d\rho u_i}{dx} = -\left(\frac{P}{A_c}\right) \rho u_w}$$

Momentum:-

$$A_c d(\rho u_i^2) = -A_c dp_i - P dx \tau_{si}$$

$$\frac{d}{dx} \rho u_i^2 = -\frac{dp_i}{dx} - \left(\frac{P}{A_c}\right) \tau_{si}$$

$$\tau_{si} = \frac{1}{2} \rho u_i^2 C_{fi} = \frac{1}{2} \rho u_i C_{fi} Re_i \frac{\mu}{\rho a}$$

$$\tau_{si} = \frac{1}{2} C_{fi} Re_i \left(\frac{\mu u_i}{a}\right)$$

$$\left(\frac{P}{A_c}\right) \tau_{si} = \left(\frac{4}{a}\right) \frac{1}{2} C_{fi} Re_i \left(\frac{\mu u_i}{a}\right)$$

$$Re = \frac{u a \rho}{\mu}$$

$$= 2 C_{fi} Re_i \left( \frac{\mu u_i}{a^2} \right)$$

There is suction effect along the walls of the inlet channel

$\Rightarrow$  the friction factor requires correction.

$$\Rightarrow C_{fi} Re_i = F_{\text{correction}} (C_{fo} Re_s) \quad Re = \frac{v a}{\nu}$$

$\approx 1$  for typical DPF condition

$$\therefore C_{fi} Re_i = (C_{fo} Re) = c$$

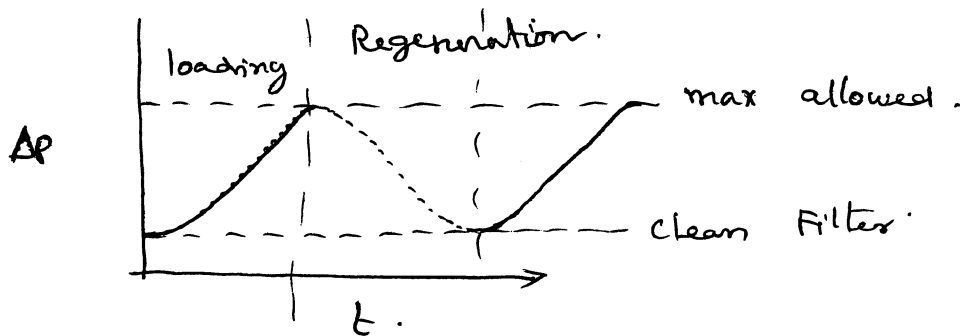
$$\Rightarrow \left( \frac{P}{A_c} \right) \tau_{si} = 2c \left( \frac{\mu u_i}{a^2} \right)$$

Now;

$$\boxed{- \frac{dp_i}{dx} = \frac{d \rho u_i^2}{dx} + 2c \left( \frac{\mu u_i}{a^2} \right)}$$

(c) Modes:-

- ~~1) Regeneration~~
- 1) loading / filtration
- 2) Regeneration.





4 (a) Volumetric effy of SI engines generally less than Diesel engines due to flow losses in the throttle (even at WOT), warmer intake manifolds leading to lower densities, fuel vapour displaces air, and the residual fraction is generally greater.

Shape of curves can be understood with reference to charge heating at lower engine speeds, frictional losses increasing as the square of engine speed, backflow reducing with higher engine speeds, and choking at very high engine speeds. Tuning effects explain some of the additional detail. Valve overlap.

(b) Contribution of PMEP to total, distinction between throttling work and valve flow work. – variation of these vs speed and load.

(c) Fluctuations in 0 to 1% burn time AFR/velocity field/EGR spatial/temporal variability/spark plug electrodes/movement of flame kernel - effect on effective start of combustion and heat release profile. Effects at extremes of mixture and timing – slow – partial – misfires. Ignition limit (Quader plot)