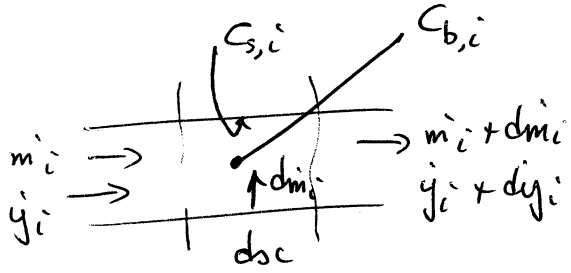


Qu1 (a) From eq 8 of the data sheet

$$d\dot{m}_i = h_{D,i} P \cdot dsc \,(C_{s,i} - C_{b,i})$$

now

$$C_i \equiv y_i \rho \frac{M_i}{M}, \text{ and}$$

$$d\dot{m}_i = dy_i \, M_i \dot{m} \frac{1}{M}$$

$$\therefore dy_i \cdot \frac{M_i \cdot \dot{m}}{M} = h_{D,i} P dsc \frac{\rho M_i}{M} (y_{s,i} - y_{b,i})$$

or

$$\dot{m} \frac{dy_i}{dsc} = h_{D,i} P \cdot \rho (y_{s,i} - y_{b,i})$$

Now $\dot{m} = \rho A u$ (per channel), and $S = \frac{P n \ell}{A n \ell (1/\epsilon)} = \frac{\epsilon P}{A}$

hence

$$\epsilon u \frac{dy_i}{dx} + h_{D,i} S (y_{b,i} - y_{s,i}) = 0$$

(b) Eliminating $\hat{R}_i$ between Eq 3 & 6 on the data sheet gives

$$y_{i,s} = y_{i,g} \left(1 + \frac{M a k_i y_{O_2}}{\rho h_{D,i} S \cdot \bar{T}}\right)^{-1}, \text{ where } G = T \text{ has been sub}^{\underline{d}} \text{ as low concentrations.}$$

Substitute for $y_{i,s}$ in eq 4, and use $\rho = \frac{p}{RT}$, gives

$$\frac{dy_{i,g}}{dx} = - y_{i,g} \frac{h_{D,i} S}{\epsilon u} \left(\frac{1}{1+\beta}\right) \quad \text{where} \quad \beta = \frac{p h_{D,i} S}{R M k a y_{O_2}}$$

Integrating, noting that y_{O_2} = const as y_g v. small, we obtain

$$y_{i,g}^{x} = y_{i,g}^{x=0} \cdot \exp\left(- \frac{h_{D,i} S}{\epsilon u (1+\beta)} x\right).$$

Now $D_{co} = 1.332E-4$ $\therefore h_{D,co} = \frac{4 \cdot 1.332E-4}{.001} = 0.533$

$S = \frac{4\epsilon}{d} = \frac{4 \cdot .7}{.001} = 2800$. $\dot{m} = \frac{p}{RT} \cdot (0.12 \cdot \epsilon) \cdot u$ (↑ FLOW AREA)

$\therefore u = \frac{0.015 \cdot 287 \cdot T}{10^5 \cdot .012 \cdot 0.7} = 5.125E-3$ $\frac{q}{S} = 10$

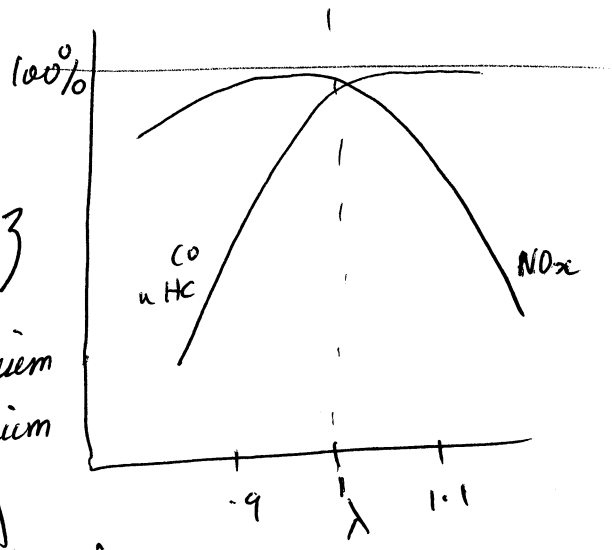
$\hat{k_c} = 6.7E10 \exp\left(\frac{-12556}{T}\right)$, $\therefore \beta = \frac{0.45E-10}{\exp\left(\frac{12556}{T}\right)}$

$$\frac{h_{D,co} \cdot S \cdot x}{\epsilon \cdot u} = \frac{62376}{T}$$

$$\therefore \ln(0.5) = -0.693 = -\frac{62376}{T\left(1 + \frac{0.45E-10}{\exp\frac{-12556}{T}}\right)}$$

A few trys give $T \simeq 570K$ (~300C)

Q2 (a) – Typical efficiency trends:



A three-way catalyst typically consists of a cordierite monolith, coated with an alumina/ceria/zirconia washcoat, which has a highly fractal surface. This surface is coated with precious metals – Pt, Pd and Rh. Platinum and/or Palladium are good promoters of oxidation, Rhodium promotes ie reduction reactions necessary to convert NOx. The characteristic efficiency curves shown are due to the requirement of excess oxygen for the oxidation reactions (uHC, CO) and excess reducing species (uHC, CO) for the reduction of NOx. Three way operation needs to be close to $\lambda = 1$ for good conversion of all three pollutants, but the oxygen storage characteristics of the ceria washcoat allow for transient excursions away from $\lambda = 1$.

Damage to the catalyst may be due to excess temperature causing loss of precious metal area, or in extreme cases loss of physical integrity of the monolith. Damage by poisoning is also common, especially from lead.

(b) using the above expression, with $y_{s,i} = 0$ (fully warmed up) assuming $T = 600°C$, $p = 1$ bar, then $\rho = \frac{10^5}{287.873} = 0.4$ kg/m³

$$\dot{m}_{max} = \frac{6500}{60.2} \cdot \frac{1.4}{10^3} \cdot 0.9 \cdot \frac{14.5+1}{14.5} \cdot 1.2 = 0.088 \text{ kg/s}$$

rpm / 60s/m 2 (↑ 4-stroke) · swept vol · vol effy · air+fuel / air · amb. density

at 50% of full power $\dot{m} = 0.044$ kg/s

So Eq 4 (data sheet) becomes — D_{HC} – must take lower ($D_{CO} > D_{HC}$)

$$\epsilon \left(\frac{0.044}{0.4 \cdot n_c \cdot d^2} \right) \frac{dy_b}{dx_c} + \left(4 \cdot \frac{0.8095E-4}{d} \right) \left(\frac{4 d \epsilon}{d^2} \right) \cdot y_b = 0$$

Integrating and simplifying

$$\ln\left(\frac{0.01}{1}\right) = -0.0115 \, l \cdot n_c \quad \therefore \quad \underline{\underline{l n_c = 400}}$$

(99%)

Take $T = 800°C$, $\mu = 4.4E-5$

Max power consideration. $\frac{df}{dx_c} = \frac{14.227 \cdot (4d)^2 \cdot \mu \cdot 287 \cdot 1073 \cdot 0.08}{8 \cdot d^6 \cdot p \cdot n_c}$

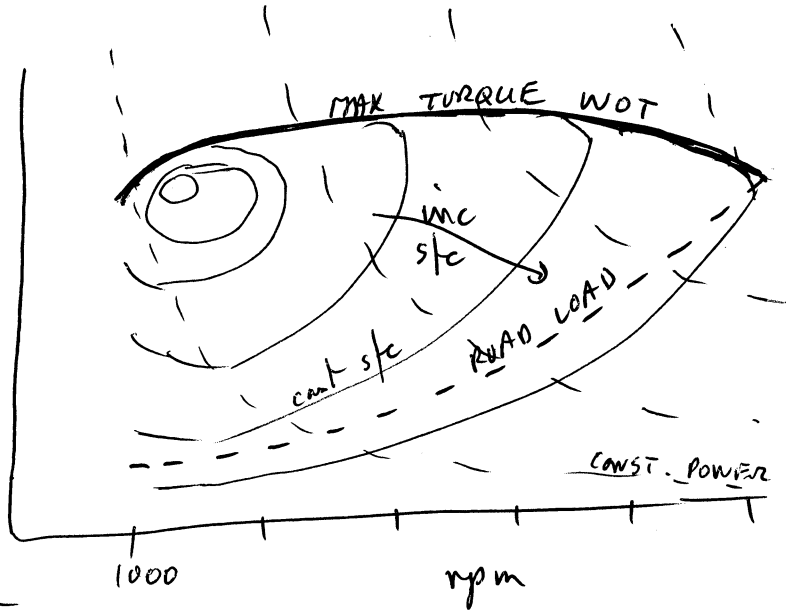
Integrating, with $p_1 = 1.3$ bar, $p_2 = 1$ bar, we find, for $d = .0006$ m

$\underline{\underline{l/n = 1.32E-5}}$. Combining this result with

that from part (i), we have $\underline{\underline{l = 72\text{mm}}}$, $\underline{\underline{n = 5454}}$.

4A5 exam 2004

Q3 (a)



MAX TORQUE

If the combustion event was identical at all speeds, the wide open throttle (WOT) torque would be a horizontal line (neglecting changes of friction torque with speed). At low rpm, it is lower because the gas exchange process is not so efficient, resulting in increased residual gases being trapped - I.e less oxygen in the cylinder, and less torque. At intermediate speeds, the torque is a maximum, as gas exchange is good. At the highest speeds, the pressure drops in the intake (especially) and exhaust system lead to lower cylinder pressures during intake, and increased back pressure during the exhaust event - all leading to lower torque (though still giving the highest power).

SFC

The specific fuel consumption contours give the best s/c at low rpm, and near WOT. This is because the engine friction power is low, and throttling losses are minimal. As rpm increases at WOT, the s/c increases (worsens) as friction power increases. Increased throttling at constant rpm leads to throttling losses, i.e. irreversible losses, giving high s/c's. At high speeds and torques, the s/c may

also decrease as fuel enrichment is used to increase power, and reduce the tendency to knock.

(ii) The road load characteristic indicates the dominant effect of drag ($\propto vel^2$ – i.e. rpm^2), and the finite value at low rpm being due to rolling resistance etc. The max rpm/torque point should be close to the end of the road load curve at max rpm.

Clearly at moderate power levels, the road load line is at far from optimum values of sfc, the 'best' point can be found by following the const. power lines to the minimum sfc points. A CVT would enable this benefit to be obtained. The downside is that the torque reserve (the vertical distance between the load point and the maximum torque line) is much smaller, and rapid torque response is impaired.

Q4

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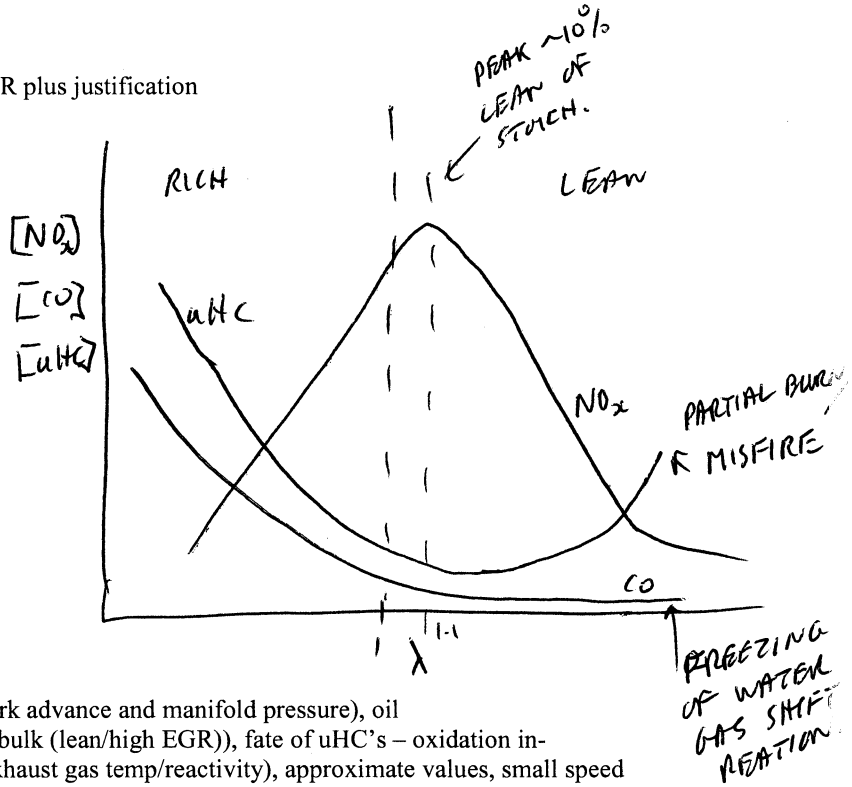
(4)

Sketch of basic trends of pollutant levels vs AFR plus justification



uHC sources discussion of

crevices (peak pressure effect on packing – spark advance and manifold pressure), oil adsorption/desorbtion, quenching (surface and bulk (lean/high EGR)), fate of uHC's – oxidation in-cylinder/exhaust port (AFR, spark effects on exhaust gas temp/reactivity), approximate values, small speed effect

CO – discussion of

rich chemistry

chemistry during expansion – oxidation mechanisms, relative rates of bimolecular vs trimolecular reactions, freezing out at above equilibrium levels. Any effects increasing uHC tend to increase CO via partial oxidation, small speed effect.

NOx – discussion of

extended Zeldovich mechanism, relative forward and reverse rates, increasing speed, decreasing time for formation, max temp changes (especially via AFR (though [O2] effect too), spark, EGR) lead to [NOx] changes, NO2 insignificant

(b)

plot of trade-off between NOx and smoke

NO forms fastest in regions close to stoichiometric. Burned gas temperature is the most important variable, oxygen availability the second most important. – In Diesel always some regions burning at close to stoichiometry. – EGR/later SOI reduce max temps. Speed decreases NO due to lower peak temps and combustion duration. NO2 significant (up to 30%) due to freezing, EGR reduces NOx, by deceasing the heat input per unit mass burning. Leaner AFR's decrease NOx mainly due to less fuel buring, and lower peak pressures (temperatures). Late SOI reduces NOx due to lower press/temps.

Particulates form in the rich combustion zones that always exist in Diesel combustion. The vast majority of the particles formed (by nucleation (after dehydrogenation, oxidation), surface growth, agglomeration, adsorption/condensation (largely by uHC's). Smoke rises with engine speed/EGR (dramatically at a certain level), late SOI. Smoke rises very sharply at AFR's approaching stoichiometry due to insufficient oxidation.