2.61 Quiz Spring, 2017

Problem 1 solution

Vehicle mass = 1500 kg; frontal area $A = 1.8 \times 1.5 = 2.7\ m^2$

Gear ratio @ 5th gear = $3.89 \times 0.64 = 2.49$; tire diameter $d = 0.63\ m$

Level road cruising at velocity $u = 65$ mph $= 29.1$ m/s

Rolling resistance $F_R = C_R M g = 0.015 \times 1500 \times 9.81 = 220.7\ N$

Drag resistance $F_D = \frac{1}{2} \rho u^2 A C_D = \frac{1}{2} \times 1.2 \times (29.1)^2 \times 2.7 \times 0.3 = 411.6\ N$

Brake Power $P_b = \frac{1}{\eta_T}[F_R + F_D]u = \frac{1}{0.85}[220.7 + 411.6] \times 29.1 = \underline{21.65\ kW}$

1) Engine Speed N: $\frac{N \pi d}{GR} = u$; $N = \frac{u\, GR}{\pi d} = \frac{29.1 \times 2.49}{\pi \times 0.63} = \underline{36.61\ Rev/s}$
$= \underline{2197\ RPM}$

BMEP: $BMEP \cdot V_D \cdot \frac{N}{2} = P_b$; $BMEP = \frac{P_b}{V_D \cdot N/2} = \frac{21.65 \times 10^3}{3 \times 10^{-3} \times 36.61/2} = \underline{3.94\ bar}$

Torque τ: $\tau \cdot 2\pi N = P_b$ $\quad \tau = \frac{P_b}{2\pi N} = \frac{21.65 \times 10^3}{2\pi \times 36.61} = \underline{94.1\ Nm}$

2) The operating point is at A on the MBP. The sfc = $\underline{290\ g/kWh}$

To find mpg: To go 1 mile, takes $\Delta t = \frac{1}{65} \times 3600$ seconds

mass of fuel used = $P_b \cdot \Delta t \cdot sfc$

vol. of fuel = $P_b \cdot \Delta t \cdot sfc \cdot \frac{1}{\rho_{fuel}} = (21.65 \times 10^3) \times \left(\frac{1}{65} \times 3600\right) \frac{290}{10^3 \times 3600} \frac{10^{-3}}{0.78} \frac{1}{3.785}$ gallon

$= 3.27 \times 10^{-2}$ gallon

mile per gallon $= \frac{1}{3.27 \times 10^{-2}} = \underline{30.6\ \text{miles per gallon}}$

3. To go from 6-cylinder/3L to 3 cylinder/1.5L engine, the BMEP has to go up twice the amount, i.e. $3.94 \times 2 = 7.88$ bar.

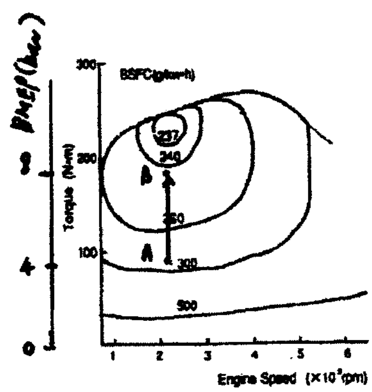
The operating pt is at B on the MAP.

(Note that the y axis is BMEP now)

The sfc is $\underline{242\ g/kWh}$

The mpg is

$30.6 \times \frac{290}{242} = \underline{36.6\ mpg}$



4) Improvement of $\frac{36.6}{30.6} = \underline{1.20}$ (mainly from unthrottling)

Problem 2 solution

Note that the total moles of reactants and products are the same, so equilibrium relationship not pressure dependent

(a) At 1900 K

$$\frac{x_{CO}\, x_{H_2O}}{x_{H_2}\, x_{CO_2}} = 10^{3.386+7.131-10.898} = 10^{0.619} = \underline{\underline{4.159}}$$

(b)

$$CH_4 + 2\lambda(O_2 + 3.773N_2) \rightarrow aCO + bCO_2 + cH_2 + dH_2O + 2\lambda(3.773N_2)$$

$x_{CO} = \frac{a}{S}$ $\quad S = (a+b+c+d+2\lambda\cdot 3.773)$

$x_{CO_2} = \frac{b}{S}$

$x_{H_2} = \frac{c}{S}$ $\qquad \frac{ad}{bc} = 4.159$

$x_{H_2O} = \frac{d}{S}$

Carbon balance $\quad a + b = 1$

Hydrogen balance $\quad c + d = 2$

Oxygen balance $\quad a + 2b + d = 4\lambda$

CO to CO_2 ratio = 3:1 $\Rightarrow$ $\frac{a}{b} = 3$; $b = \underline{\underline{0.25}}$; $a = \underline{\underline{0.75}}$

$\frac{a}{b}\frac{d}{c} = 4.159 \Rightarrow \frac{d}{c} = \frac{4.159}{3} = 1.386$; $c + d = 2 \Rightarrow c = \underline{\underline{0.838}}$

$d = \underline{\underline{1.162}}$

(c) $a + 2b + d = 4\lambda \Rightarrow \lambda = \underline{\underline{0.604 \text{ (or phi=1.66)}}}$

$$CH_4 + 2\underbrace{(0.604)}_{\lambda}(O_2 + 3.773N_2) \rightarrow 0.75CO + 0.25CO_2 + 0.838H_2 + 1.162H_2O + 2\times 0.604\times 3.773N_2$$

(d)

$$Q = \sum(N_i\, \Delta h^{o}_{f\,i})_{reactants} - \sum(\ )_{products}$$

$$= (-74.9) - \{\underbrace{a(-110.5)}_{-82.875} + \underbrace{b(-393.5)}_{-98.375} + \underbrace{d(-241.8)}_{-280.972}\}$$

=387.3 MJ/k-mol CH4
or 387.3/16
=24.2 MJ/kg-CH4

(e) Combustion efficiency $= \frac{24.2}{50} = \underline{48.4\%}$

This is the same value as one would get by 1-(sum of exhaust LHV)/(LHV of fuel)