Solution to Quiz

Problem 1

Vehicle: mass $M = 1500$ kg

Frontal area $A = 1.8 \times 1.5 = 2.7 m^2$

Gear ratio @ 5^{th} gear $= 3.89 \times 0.64 = 2.49$

Level road cruising at velocity $u = 35$ mph $= 15.7$ m/s

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

Drag resistance $F_D = \frac{1}{2}\rho u^2 A C_D = \frac{1}{2} \times 1.2 \times (15.7)^2 \times 2.7 \times 0.3 = 119.8 N$

Brake power $P_b = \frac{1}{\eta_T}[F_R + F_D]u = \frac{1}{0.85}[220.7 + 119.8]15.7 = \underline{6.29 \text{ kW}}$

1) Engine speed N: $\frac{N \pi d}{(GR)} = u$ (d = tire diameter) or $N = \frac{u(GR)}{\pi d} = \frac{15.7 \times 2.49}{\pi\, 0.632} = \underline{19.69 \text{ rev/s}}$ ($\underline{1181 \text{ rpm}}$)

$P_b = BMEP \cdot V_D \cdot \frac{N}{2} \Rightarrow BMEP = \frac{P_b}{V_D \cdot \frac{N}{2}} = \frac{6.29 \times 10^3}{2.5 \times 10^{-3} \times \frac{19.69}{2}}$

$= \underline{2.56 \text{ bar}}$

2) The operating point is at (A) on the engine map.

The sfc is $\underline{275 \text{ g/kWh}}$

To travel 1 mile, time $\Delta t = \frac{1}{35}$ hr

energy required $= P_b \Delta t = \frac{6.29}{35}$

$= 0.180$ kWh

Fuel required $= 0.180 \times 275 = 49.4$ g

Vol of fuel $= 61.8$ cc $= \frac{61.8 \times 10^{-3}}{3.785}$ gallon

$= 1.60 \times 10^{-2}$ gallon

Thus mpg $= \frac{1}{1.6 \times 10^{-2}} = \underline{61.5 \text{ mpg}}$

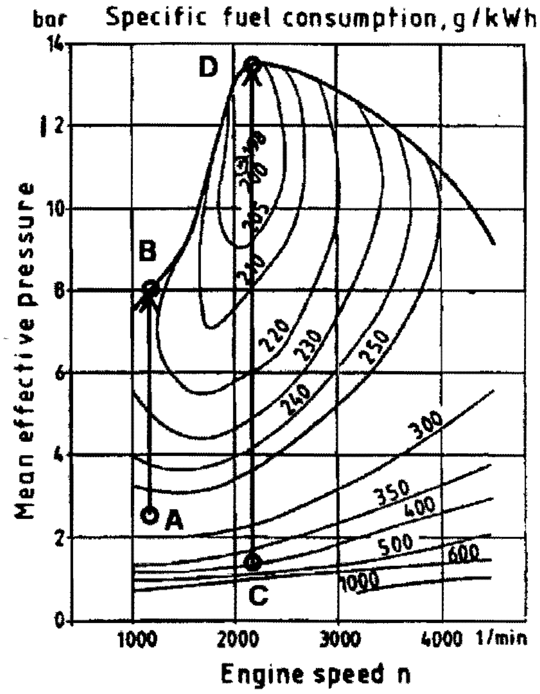
3) $P_b = \frac{1}{\eta_T}[F_R + F_D + M\frac{dV}{dt}]u$

WOT at 1180 rpm $\rightarrow$ BMEP = 8 bar (B)

$P_b = 8 \times 10^5 \times 2.5 \times 10^{-3} \times (\frac{19.69}{2}) = 19.7$ kW

$\frac{dV}{dt} = \frac{[\frac{\eta_T P_b}{u} - F_R - F_D]}{M} = \frac{(\frac{0.85 \times 19.7 \times 10^3}{15.7} - 119.8 - 220.7)}{1500}$

$= \underline{0.48 \text{ m/s}^2}$



4) 3^{rd} Gear ; gear ratio $GR = 3.89 \times 1.19 = 4.63$

$$N = \frac{u\,(GR)}{\pi d} = \frac{15.7 \times 4.63}{\pi\ 0.632} = \underline{\underline{36.73\ rev/s}} = \underline{\underline{2204\ rpm}}$$

$$BMEP = (F_R + F_D)\frac{u}{\eta_T}\frac{2}{N}\frac{1}{V_D} = (119.8 + 200.7)\frac{15.7}{0.85}\frac{2}{36.73}\frac{1}{2.5\times10^{-3}} = \underline{\underline{1.37\ bar}}$$

The operating point before flooring the gas is at point (C).

At WOT @ 2204 rpm, BMEP = 13.5 bar (point (D) in the figure)

$$P_b = BMEP\ V_D\ \frac{N}{2} = 13.5\times10^5 \times 2.5\times10^{-3}\ \frac{36.73}{2} = 62\ kW$$

$$\frac{du}{dt} = \frac{1}{M}\left(\frac{\eta_T P_b}{u} - F_R - F_D\right) = \frac{1}{1500}\left[\frac{0.85\times 62\times10^3}{15.7} - 200.7 - 119.8\right] = \underline{\underline{2.01\ m/s^2}}$$

Note the much higher power comes from (a) the engine speed N is higher and (b) that the BMEP at WOT at the higher N is larger.

Problem 2

Heat release at 298K, 1 Atm $= (\sum N_i \Delta h^0_{f,i})_R - (\sum N_i \Delta h^0_{f,i})_P$

(a) $C + \frac{1}{2} O_2 \longrightarrow CO$

$Q_{release} = (0) - (-110.5) = 110.5$ MJ/Kmol of C ; exothermic

(b) $H_2O(liq) + CO \rightarrow H_2 + CO_2$

$Q_{release} = [(-285.8) + (-110.5)] - [-393.5] = -2.8$ MJ/Kmol of CO; slightly endothermic

(c) Reactants: 1 mol of H_2O, 1 mol of CO $\longrightarrow$ Products: a mole of H_2O, b mole of CO, c mole of H_2, d mole of CO_2

Equil const at 800K

$k = 10^{(0+25.83)-(8.29+11.91)}$

$= 10^{0.63} = 4.27$

Equilibrium

$H_2O + CO \rightleftharpoons H_2 + CO_2$ Thus $\frac{cd}{ab} = k = 4.27$

Carbon balance $b + d = 1$ (i)

Hydrogen balance $a + c = 1$ (ii)

Oxygen balance $a + b + 2d = 2$ (iii)

(i) + (ii) − (iii) $\Rightarrow c = d$

substitute into (ii) and subtract from (i)

$\Rightarrow a = b$

Thus equilibrium : $\frac{c^2}{a^2} = k$; substitute into (ii) $\Rightarrow a = \frac{1}{1+\sqrt{k}}$

Therefore $a = \frac{1}{1+\sqrt{4.27}} = 0.326$ (H_2O) ; $b = 0.326$ (CO) ; $c = 0.674$ (H_2) ; $d = 0.674$ (CO_2)

(d) $H_2O(liq) + CO \rightarrow 0.326(H_2O + CO) + 0.674(H_2 + CO_2)$

$Q_{release} = [(-285.8) + (-110.5)] - \{0.326[(-241.8) + (-110.5)] + 0.674(-393.5)\}$

$= (-396.3) - \{(-114.85) + (-265.2)\}$ (−380.07)

$= -16.23$ MJ/Kmol of CO in feed stream ; slightly endothermic

(e) $3CO + 3H_2 \rightarrow C_2H_6O + CO_2$

$Q_{release} = 3[(-110.5)] - [(-184.1) + (-393.5)]$

$= (-331.5) - (-577.6) = 246.1$ MJ/Kmol of DME

exothermic

(f) The reactions are

Ⓐ $C + \frac{1}{2}O_2 \rightarrow CO$

Ⓑ $H_2O(liq) + CO \rightarrow 0.326(H_2O + CO) + 0.674(H_2 + CO_2)$

Ⓒ $3CO + 3H_2 \rightarrow C_2H_6O + CO_2$

To make 1 mole of DME takes:

- 1 cycle of Ⓒ
- (3/0.674) cycles of Ⓑ to make the H_2
- The above step would generate $\left(\frac{3}{0.674} \times 0.326\right)$ mole of CO, so to make up for the CO required in Ⓑ, needs $3 - \left(\frac{3}{0.674} \times 0.326\right)$ cycles of Ⓐ
- Need 3/0.674 cycles of Ⓐ to produce CO for Ⓑ

Summary:

1 cycle of Ⓒ $= 1$

$\frac{3}{0.674}$ cycles of Ⓑ $= 4.45$

$3 - \left(\frac{3}{0.674} \times 0.326\right) + \frac{3}{0.674}$ cycles of Ⓐ $= 6$

Energy released

$$Q_{rel} = \underbrace{(246.1)}_{(C)} + 4.45\underbrace{(-16.23)}_{(B)} + \underbrace{6\,(+110.5)}_{(A)} = \underline{\underline{836.9\ MJ}}/\text{Kmol of DME}$$

Compared to burning directly the 6 mole of C used in the 6 cycles of (A).

$$6C + 6O_2 \rightarrow 6CO_2$$

Energy released $= 6(-393.5) = 2361\ MJ$

The heating value of DME (1 Kmole) is

$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O$ Energy release $= 1328.3\ MJ/\text{Kmol DME}$

The difference is in the heat release in the production (836.9 MJ) and the energy used to vaporized the liq water

$$\frac{3}{0.674}(\underset{liq}{285.8} - \underset{vap}{241.8}) = 195.85$$

Δh_f of H_2O

$$\underbrace{1328.3}_{\substack{\text{DME}\\\text{heating}\\\text{value}}} + \underbrace{836.9}_{\substack{\text{energy}\\\text{released}\\\text{in}\\\text{process}}} + \underbrace{195.9}_{\substack{\text{vaporizing}\\\text{the}\\\text{water}}} = 2361 \text{ — checks}$$

2.61 Internal Combustion Engines
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