Homework #5 solution

6.1 (a) Mixture of 1 mole H_2 to 1 mole iC_8H_{18}

$$H_2 + C_8H_{18} + 13(O_2 + 3.773N_2) \rightarrow 10H_2O + 8CO_2 + 49.05N_2$$

Stoich. air fuel ratio $= \frac{13 \times 4.773 \times 28.96}{2+114} = \underline{15.5}$ (compared with 15.13 with neat iC_8)

(b) Heating value of fuel $Q_{LHV} = \frac{2 \times 120 + 114 \times 44.4}{2+114} = \underline{\underline{45.7\ MJ/kg}}$

(c) Relate BMEP to known quantities

(*) $$BMEP = \eta_{f,i,g}\ \eta_m\ \eta_v \left(\frac{\rho_{a,o}}{A/F}\right)\frac{LHV}{V_D} \quad ; \quad \eta_m = \frac{BMEP}{BMEP + PMEP + FMEP}$$

The PMEP may be estimated by $p_e - p_i$

The volumetric efficiency difference is due to only quasi-static effects

$$\eta_v = \underbrace{\left(\frac{W}{W_A}\right)\left(\frac{1}{1+F/A}\right)}\left(\frac{p_i}{p_{ao}}\right)\underbrace{\left(\frac{T_{ao}}{T_i}\right)\left(\frac{T_i}{T_1}\right)(1-x_r)\left(\frac{r_c}{r_c-1}\right)}_{\text{assume same for both cases}}$$

$$\frac{W}{W_A}\frac{A}{A+F} = \underbrace{\frac{W}{W_A}\frac{A}{A+F+R}}_{=\tilde{x}_a}\ \underbrace{\frac{A+F+R}{A+F}}_{=\frac{1}{1-x_r}}$$

$\tilde{x}_a$: mole fraction of air in inducted fresh charge

x_r = residual mass fraction (same for both cases)

Case (1) C_8H_{18} at $\phi = 0.8$

$$C_8H_{18} + \frac{12.5}{0.8}(O_2 + 3.773N_2) \rightarrow 8CO_2 + 9H_2O + 58.95N_2 + 3.13O_2 \ ; \ \tilde{x}_a = 0.987$$

Case (2) $C_8H_{18} + H_2$ at $\phi = 0.5$

$$C_8H_{18} + H_2 + \frac{13}{0.5}(O_2 + 3.773N_2) \rightarrow 8CO_2 + 10H_2O + 98.1N_2 + 6.5O_2 \ ; \ \tilde{x}_a = 0.984$$

← same

The $\tilde{x}_a$ values are about the same because at fuel lean, it is mostly air

Thus $$\frac{\eta_{v_2}}{\eta_{v_1}} = \frac{x_{a_2}}{x_{a_1}}\frac{p_{i2}}{p_{i1}} \simeq \frac{p_{i2}}{p_{i1}}$$

Comparing at the same BMEP = 2.75 bar

Using (*) $$1 = \frac{BMEP_2}{BMEP_1} = \frac{\eta_{f,g_2}}{\eta_{f,g_1}}\frac{(BMEP + FMEP + PMEP)_1}{(BMEP + FMEP + p_E - p_{i_2})_2}\frac{p_{i2}}{p_{i1}}\frac{(A/F)_1}{(A/F)_2}\frac{LHV_2}{LHV_1}$$

Put in numerical values: $$1 = \frac{0.4}{0.35}\left(\frac{2.75 + 1.38 + 0.55}{2.75 + 1.38 + 1 - p_{i_2}}\right)\left(\frac{p_{i2}}{1}\right)\frac{15.13\left(\frac{1}{.8}\right)}{15.5\left(\frac{1}{.5}\right)}\frac{45.7}{44.3}$$

solving: $\underline{\underline{p_{i2} = 0.62\text{ bar}}}$ $\quad PMEP_2 = 1 - 0.62 = \underline{\underline{0.38\text{ bar}}}$

Problem 2) The unburned and burned gas temperatures are tabulated. (parts (i) - (iii))

(iii) The laminar flame speed is

$$S_L = S_{L0}\left(\frac{T_u}{T_0}\right)^{\alpha}\left(\frac{p}{p_0}\right)^{\beta} f \qquad \text{where } f = 0.4 \text{ for a residual mole fraction of } 20\%$$

$$\alpha = 2.4 - 0.271\,\phi^{3.51}$$

$$\beta = -0.357 + 0.14\,\phi^{2.77}$$

$$S_{L0} = 30.5 + (-54.9)(\phi - 1.21)^2$$

(cm/s)

(iv) Expansion velocity

uniform pressure

$$S_E = S_L\left(\frac{\rho_u}{\rho_b}\right) = S_L\left(\frac{T_b}{T_u}\right)$$

(v) $\frac{d}{d\theta}(x_b)$ can be found by finite difference

(vi) Unburned gas vol. $V_u = m_u R_u T_u$

burned gas vol. $V_b = m_b R_b T_b$

$$\Rightarrow \left(\frac{1-\frac{V_b}{V}}{V_b/V}\right) = \frac{(1-x_b)}{x_b}\,\frac{W_b}{W_u}\,\frac{T_u}{T_b}$$

where W_u and W_b are the molecular weights. Thus

$$\left(\frac{V_b}{V}\right) = 1\bigg/\left[1 + \left(\frac{1}{x_b} - 1\right)\frac{W_b}{W_u}\,\frac{T_u}{T_b}\right]$$

For stoichiometric gasoline combustion: $\{W_b = 28.98 \simeq 29$

For gasoline, $(C_{7.9}H_{1.87\times7.9})$ at $\lambda = 1$ $\quad\big[\ W_{u,f} = 30$ for fresh mixture

MW=110, H/c = 1.87

$$C_{7.9}H_{14.8} + 11.6\,(O_2 + 3.773N_2) \rightarrow 7.9CO_2 + 7.4H_2O + 43.8N_2$$

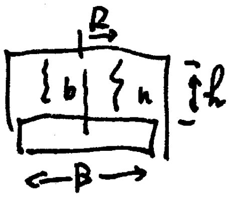
$$W_u = W_{u_f}\,\tilde{x}_r + (1-\tilde{x}_r) + W_b(\tilde{x}_r)$$

$$= 30 \times (1-0.2) + 29\,(0.2)$$

$$= 29.80$$

(v) The burned gas volume $V_b = (\pi R^2)\,h$

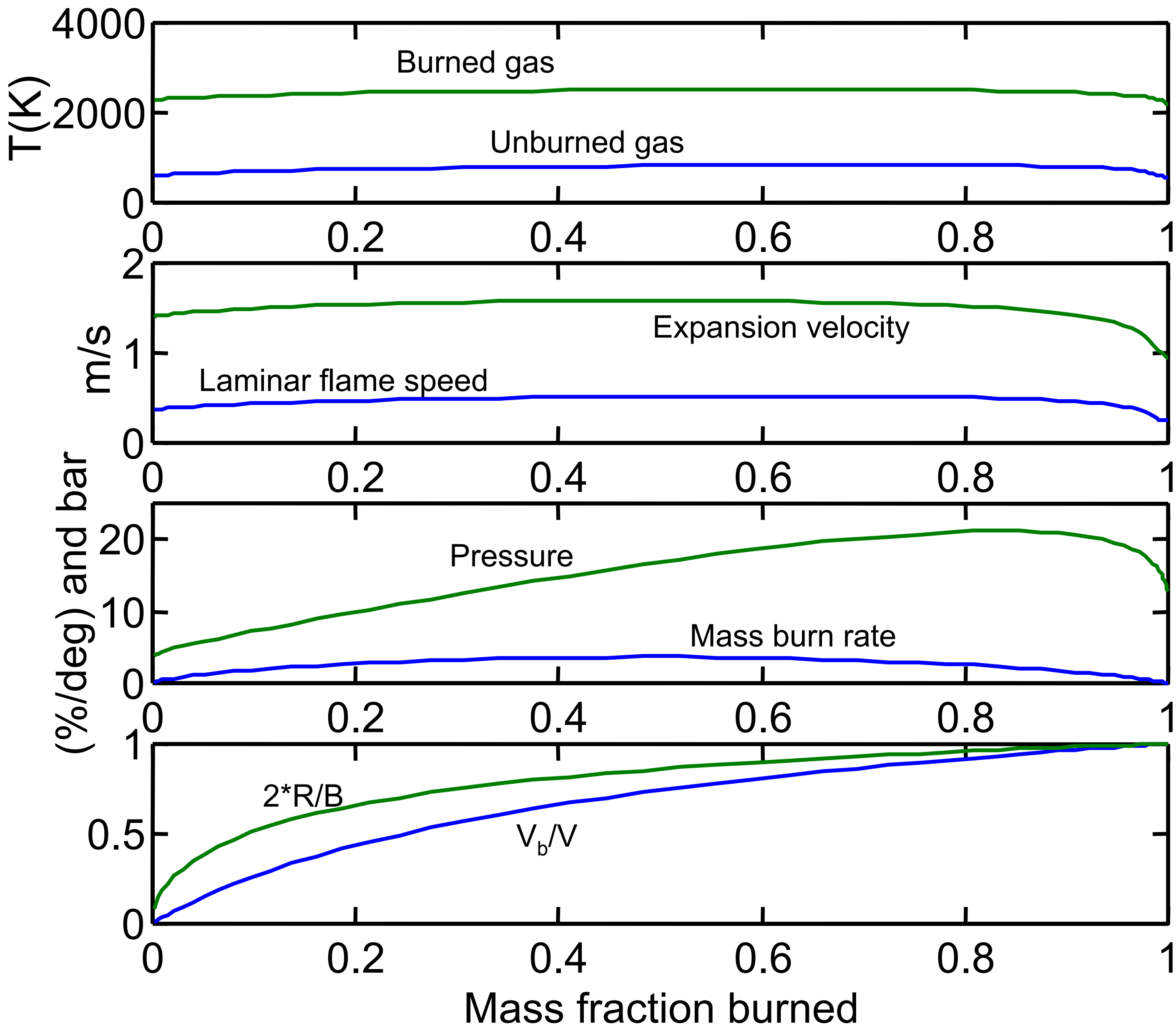
The chamber volume $V = \left(\frac{\pi B^2}{4}\right) h$



Thus $\left(\frac{V_b}{V}\right) = \left(\frac{2R}{B}\right)^2$

$$\frac{R}{B} = \frac{1}{2}\sqrt{\left(\frac{V_b}{V}\right)}$$

The various quantities are plotted on the next page.



4000
2000
0
T(K)
Burned gas
Unburned gas
0
0.2
0.4
0.6
0.8
1
2
1
0
m/s
Expansion velocity
Laminar flame speed
20
10
0
(%/deg) and bar
Pressure
Mass burn rate
1
0.5
2*R/B
V_b/V
Mass fraction burned

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2.61 Internal Combustion Engines
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