SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 14

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FUNDAMENTALS

of

Thermodynamics

Sixth Edition

CHAPTER 14

CONTENT CHAPTER 14

SUBSECTION	PROB NO.
Correspondence table	
Concept-Study Guide Problems	122-123
Fuels and the Combustion Process	124-125
Energy Equation, Enthalpy of Formation	126-133
Enthalpy of Combustion and heating Value	134-135
Adiabatic Flame Temperature	136-142
Second Law for the Combustion Process	143-145
Problems Involving Generalized Charts or Real Mixtures	146-147
Fuel cells	148
Combustion Efficiency	149-150
Review Problem	151

New	5th	SI	New	5th	SI	New	5th	SI
122	new	11	132	86	52	142	91	83
123	new	13	133	92	53	143	new	87
124	75	34	134	new	64	144	94	93
125	76	39	135	93	66	145	95	94
126	78	41	136	new	71	146	80	97
127	79	42	137	new	73	147	83	98
128	82	45	138	87	78	148	98	104
129	84	49	139	88	77	149	96	110
130	85	50	140	89	81	150	97	111
131	77	51	141	90	82	151	81	112

Concept Problems

14.122E

What is the enthalpy of formation for oxygen as O_2? If O?   For CO_2?

From Table F.6

$$\bar{h}^{\circ}_{f\,O2} = 0$$

$$\bar{h}^{\circ}_{f\,O} = 107\ 124\ \text{Btu/lbmol}$$

$$\bar{h}^{\circ}_{f\,CO2} = -169\ 184\ \text{Btu/lbmol}\quad \text{(or Table F.11)}$$

14.123E

What is the higher heating value, HHV, of n-Butane?

Either convert units from Table 14.3 or compute from the enthalpy of formation.
From Table F.11

$$\bar{h}^{\circ}_{f\,C4H10} = -\ 54\ 256\ \text{Btu/lbmol,}\qquad M = 58.124$$

$$\bar{h}^{\circ}_{f\,H2O\,liq} = -122\ 885\ \text{Btu/lbmol}\quad \text{(we need liquid for higher heating value)}$$

$$\bar{h}^{\circ}_{f\,CO2} = -169\ 184\ \text{Btu/lbmol}$$

$$\begin{aligned}
\text{HHV} = -H^{\circ}_{RP} &= \bar{h}^{\circ}_{f\,C4H10} - 4\,\bar{h}^{\circ}_{f\,CO2} - 5\,\bar{h}^{\circ}_{f\,H2O\,liq}\\
&= -\ 54\ 256 - 4(-169\ 184) - 5(-122\ 885)\\
&= 1\ 236\ 905\ \text{Btu/lbmol} = 21\ 280\ \text{Btu/lbm}\\
&= 49\ 500\ \text{kJ/kg} = 21\ 280\ \text{Btu/lbm}\quad \text{(from Table 14.3)}
\end{aligned}$$

Fuels and the Combustion Process

14.124E

Pentane is burned with 120% theoretical air in a constant pressure process at 14.7 lbf/in^2. The products are cooled to ambient temperature, 70 F. How much mass of water is condensed per pound-mass of fuel? Repeat the answer, assuming that the air used in the combustion has a relative humidity of 90%.

$$C_5H_{12} + 1.2 \times 8 \left(O_2 + 3.76\,N_2\right) \rightarrow 5\,CO_2 + 6\,H_2O + 0.96\,O_2 + 36.1\,N_2$$
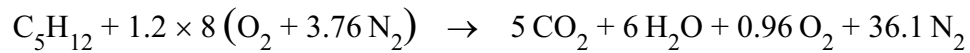
Products cooled to 70 F, 14.7 lbf/in^2

a) for H_2O at 70 F: $P_G = 0.3632$ lbf/in^2

$$y_{H2O\ MAX} = \frac{P_G}{P} = \frac{0.3632}{14.7} = \frac{n_{H2O\ MAX}}{n_{H2O\ MAX} + 42.06}$$

Solving, $n_{H2O\ MAX} = 1.066 < n_{H2O}$

Therefore, $n_{H2O\ VAP} = 1.066$, $n_{H2O\ LIQ} = 6 - 1.066 = 4.934$

$$m_{H2O\ LIQ} = \frac{4.934 \times 18.015}{72.151} = \textbf{1.232 lbm/lbm fuel}$$

b) $P_{v1} = 0.9 \times 0.3632 = 0.3269$ lbf/in^2

$$w_1 = 0.622 \times \frac{0.3269}{14.373} = 0.014\ 147$$

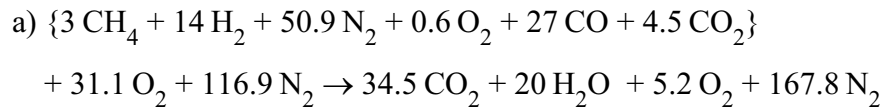$$n_{H2O\ IN} = 0.014147 \times \frac{28.97}{18.015} \times (9.6 + 36.1) = 1.040\ lbmol$$

$$n_{H2O\ OUT} = 1.04 + 6 = 7.04$$

$$n_{H2O\ LIQ} = 7.04 - 1.066 = 5.974\ lb\ mol$$

$$n_{H2O\ LIQ} = \frac{5.974 \times 18.015}{72.151} = \textbf{1.492 lbm/lbm fuel}$$

14.125E

The output gas mixture of a certain air-blown coal gasifier has the composition of producer gas as listed in Table 14.2. Consider the combustion of this gas with 120% theoretical air at 14.7 lbf/in.^{2} pressure. Find the dew point of the products and the mass of water condensed per pound-mass of fuel if the products are cooled 20 F below the dew point temperature?

a) $\{3\,CH_4 + 14\,H_2 + 50.9\,N_2 + 0.6\,O_2 + 27\,CO + 4.5\,CO_2\}$

$+\ 31.1\,O_2 + 116.9\,N_2 \rightarrow 34.5\,CO_2 + 20\,H_2O\ + 5.2\,O_2 + 167.8\,N_2$

Products:

$$y_{H2O} = y_{H2O\ MAX} = \frac{P_G}{14.7} = \frac{20}{34.5 + 20 + 5.2 + 167.8}$$

$$\Rightarrow P_G = 1.2923\ \text{lbf/in}^2 \rightarrow T_{DEW\ PT} = \textbf{110.4 F}$$

b) At $T = 90.4$ F, $P_G = 0.7089\ \text{lbf/in}^2$

$$y_{H2O} = \frac{0.7089}{14.7} = \frac{n_{H2O}}{n_{H2O} + 34.5 + 5.2 + 167.8} \quad \Rightarrow \quad n_{H2O} = 10.51$$

$$\Rightarrow n_{H2O\ LIQ} = 20 - 10.51 = 9.49\ \text{lb mol}$$

$$m_{H2O\ LIQ} = \frac{9.49(18)}{3(16)+14(2)+50.9(28)+0.6(32)+27(28)+4.5(44)}$$

$$= \textbf{0.069 lbm/lbm fuel}$$

Energy and Enthalpy of Formation

14.126E
A rigid vessel initially contains 2 pound mole of carbon and 2 pound mole of oxygen at 77 F, 30 lbf/in.^{2}. Combustion occurs, and the resulting products consist of 1 pound mole of carbon dioxide, 1 pound mole of carbon monoxide, and excess oxygen at a temperature of 1800 R. Determine the final pressure in the vessel and the heat transfer from the vessel during the process.
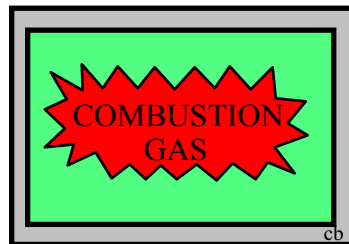
$$2\,C + 2\,O_2 \rightarrow 1\,CO_2 + 1\,CO + \frac{1}{2}O_2$$
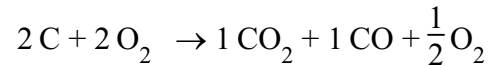
V = constant, C: solid, $n_{1(GAS)} = 2$, $n_{2(GAS)} = 2.5$

$$P_2 = P_1 \times \frac{n_2 T_2}{n_1 T_1} = 30 \times \frac{2.5 \times 1800}{2 \times 536.7} = \mathbf{125.8}\ \frac{\mathbf{lbf}}{\mathbf{in^2}}$$

$H_1 = 0$

$$H_2 = 1(-169184 + 14358) + 1(-47518 + 9323) + \frac{1}{2}(0 + 9761) = \textbf{-188 141 Btu}$$

$$_1Q_2 = (U_2 - U_1) = (H_2 - H_1) - n_2\bar{R}T_2 + n_1\bar{R}T_1$$
$$= (-188\ 141 - 0) - 1.98589(2.5 \times 1800 - 2 \times 536.67) = \textbf{-194 945 Btu}$$

14.127E

In a test of rocket propellant performance, liquid hydrazine (N_2H_4) at 14.7 lbf/in.^{2}, 77 F, and oxygen gas at 14.7 lbf/in.^{2}, 77 F, are fed to a combustion chamber in the ratio of 0.5 lbm O_2/lbm N_2H_4. The heat transfer from the chamber to the surroundings is estimated to be 45 Btu/lbm N_2H_4. Determine the temperature of the products exiting the chamber. Assume that only H_2O, H_2, and N_2 are present. The enthalpy of formation of liquid hydrazine is +21 647 Btu/lb mole.

$$N_2H_4 + \frac{1}{2}O_2 \rightarrow H_2O + H_2 + N_2$$
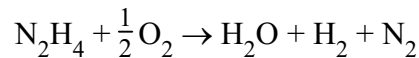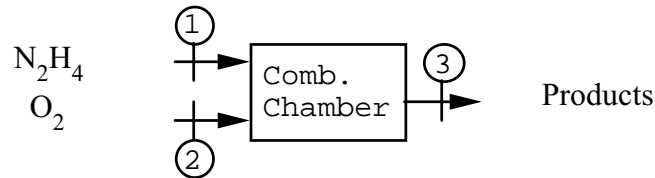
$$\dot{m}_{O2}/\dot{m}_{N2H4} = 0.5 = 32\dot{n}_{O2}/32\dot{n}_{N2H4} \quad \text{and} \quad \dot{Q}/\dot{m}_{N2H4} = -45 \text{ Btu/lbm}$$

$$\Rightarrow \quad Q_{CV} = -45 \times 32.045 = -1442 \frac{\text{Btu}}{\text{lb mol fu}}$$

C.V. combustion chamber: $\quad \dot{n}_{Fu}\bar{h}_1 + \dot{n}_{O_2}\bar{h}_2 + \dot{Q}_{CV} = \dot{n}_{tot}\bar{h}_3$

- or - $\quad H_1 + H_2 + Q_{CV} = H_{P3} \quad \Rightarrow \quad H_R^{\circ} + Q_{CV} = H_P^{\circ} + \Delta H_{P3}$

$$\Delta H_{P3} = H_R^{\circ} - H_P^{\circ} + Q_{CV} = 21\ 647 + 103\ 966 - 1442 = 124\ 171 \frac{\text{Btu}}{\text{lb mol fuel}}$$

Trial and error on T_3:

$$T_3 = 5000 \text{ R} \Rightarrow \quad \Delta H_P = 120\ 071,$$

$$T_3 = 5200 \text{ R} \Rightarrow \quad \Delta H_P = 126\ 224$$

Interpolate $\quad \Rightarrow T_3 = \textbf{5133 R}$

14.128E

One alternative to using petroleum or natural gas as fuels is ethanol (C_2H_5OH), which is commonly produced from grain by fermentation. Consider a combustion process in which liquid ethanol is burned with 120% theoretical air in a steady flow process. The reactants enter the combustion chamber at 77 F, and the products exit at 140 F, 14.7 lbf/in.^{2}. Calculate the heat transfer per pound mole of ethanol, using the enthalpy of formation of ethanol gas plus the generalized tables or charts.

$$C_2H_5OH + 1.2 \times 3(O_2 + 3.76N_2) \rightarrow 2CO_2 + 3H_2O + 0.6O_2 + 13.54N_2$$
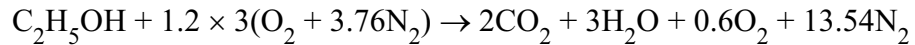
Products at 140 F, 14.7 lbf/in^2,

$$y_{H2O} = 2.892/14.7 = n_v/(2 + 0.6 + n_v + 13.54)$$

$$n_v = 3.953 > 3 \quad \Rightarrow \quad \text{no condensation}$$

$\bar{h}_f^\circ = $ -101 032 Btu/lbmol as gas

$$T_r = 536.67/925 = 0.58 \quad \Rightarrow \quad D.2: \quad \Delta h/RT_c = 5.23$$

$H_R = $ -101032 - 5.23 × 1.98589 × 925 + 0 + 0 = -110639 Btu/ lbmol fuel
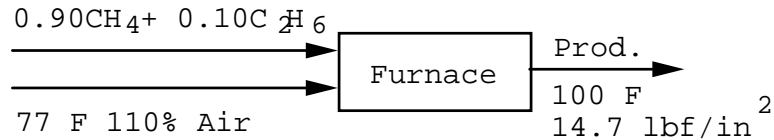
$H_P = $ 2(-169184 + 570) + 3(-47518 + 506.5)
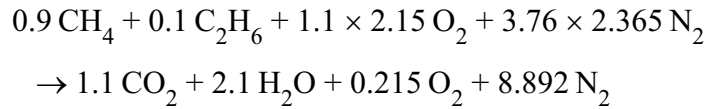
$\qquad$ + 0.6(443.7) + 13.54(438.4) = -472060 Btu/ lbmol fuel

$Q_{CV} = H_P - H_R = $ **-361421 Btu/lbmol fuel**

14.129E

In a new high-efficiency furnace, natural gas, assumed to be 90% methane and 10% ethane (by volume) and 110% theoretical air each enter at 77 F, 14.7 lbf/in.^{2}, and the products (assumed to be 100% gaseous) exit the furnace at 100 F, 14.7 lbf/in.^{2}. What is the heat transfer for this process? Compare this to an older furnace where the products exit at 450 F, 14.7 lbf/in.^{2}.

```
0.90CH 4+ 0.10C 2H 6
                              ┌─────────┐    Prod.
─────────────────────────►    │ Furnace │───►
─────────────────────────►    │         │    100 F
                              └─────────┘    14.7 lbf/in 2
77 F 110% Air
```

H_R = 0.9(-32190) + 0.1(-36432) = -32614 Btu

0.9 CH$_4$ + 0.1 C$_2$H$_6$ + 1.1 × 2.15 O$_2$ + 3.76 × 2.365 N$_2$

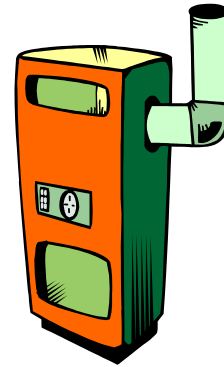→ 1.1 CO$_2$ + 2.1 H$_2$O + 0.215 O$_2$ + 8.892 N$_2$

a) T_P = 100 F

H_P = 1.1(-169184 + 206) + 2.1(-103966 + 185)

+ 0.215(162) + 8.892(160) = -402360 Btu, assuming all gas

Q_{CV} = H_P - H_R = **-369 746 Btu/lb mol fuel**

b) T_P = 450 F

H_P = 1.1(-169184 + 3674) + 2.1(-103966 + 3057)

+ 0.215(2688) + 8.892(2610) = -370 184 Btu

Q_{CV} = H_P - H_R = **-337 570 Btu/lb mol fuel**

14.130E

Repeat the previous problem, but take into account the actual phase behavior of the products exiting the furnace.

Same as 14.84 , except possible condensation.

a) 100 F, 14.7 lbf/in^2

$y_{v\ max}$ = 0.9503 / 14.7 = $n_{v\ max}$/[$n_{v\ max}$ + 10.207]

$n_{v\ max}$ = 0.705 $\Rightarrow$ n_v = 0.705; n_{liq} = 2.1 - 0.705 = 1.395

H_{liq} = 1.395[-122 885 + 18.015(68.05 - 45.09)] = -170 847 Btu/lbmol

H_{gas} = 1.1(-169 184 + 206) + 0.705(-103 966 + 185)

$\qquad$ + 0.215(162) + 8.892(160) = -257 584 Btu/lbmol

H_P = H_{liq} + H_{gas} = -428 431 Btu/lbmol

Q_{CV} = H_P - H_R = **-395817 Btu/lbmol fuel**

b) T_P = 450 F, no condensation

H_P = 1.1(-169 184 + 3674) + 2.1(-103 966 + 3057)

$\qquad\qquad$ + 0.215(2688) + 8.892(2610)

$\qquad$ = -370 184 Btu/lbmol

Q_{CV} = H_P - H_R = **-337 570 Btu/lbmol fuel**
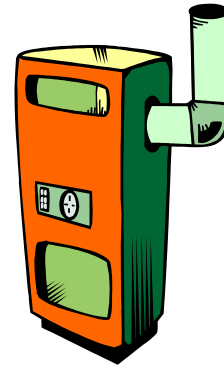
14.131E

Pentene, C_5H_{10} is burned with pure oxygen in a steady state process. The products at one point are brought to 1300 R and used in a heat exchanger, where they are cooled to 77 F. Find the specific heat transfer in the heat exchanger.

$$C_5H_{10} + \nu_{O_2}O_2 \rightarrow 5\ CO_2 + 5\ H_2O, \quad \text{stoichiometric: } \nu_{O_2} = 7.5$$
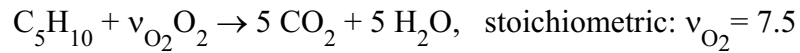
Heat exchanger in at 1300 R, out at 77 F, so some water will condense.

$$5\ H_2O \rightarrow (5 - x)H_2O_{liq} + x\ H_2O_{vap}$$
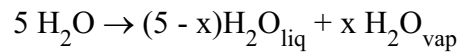
$$y_{H2O_{max}} = \frac{P_{g\ 77}}{P_{tot}} = \frac{0.464}{14.696} = 0.03158 = \frac{x}{5 + x} \qquad \Rightarrow \qquad x = 0.163$$

$$q = \frac{Q}{\dot{n}_{fuel}} = 5\left(\bar{h}_{ex} - \bar{h}_{in}\right)_{CO_2} + 5\left(\bar{h}_{ex} - \bar{h}_{in}\right)_{H2O_{vap}} - (5 - x)\bar{h}_{fg\ H2O}$$

$$= \textbf{-164340}\ \frac{\textbf{Btu}}{\textbf{lb mol fuel}}$$

14.132E

Methane, CH_4, is burned in a steady state process with two different oxidizers: **A**. Pure oxygen, O_2 and **B** a mixture of $O_2 + x$ Ar. The reactants are supplied at T_0, P_0 and the products in are at 3200 R both cases. Find the required equivalence ratio in case **A** and the amount of Argon, x, for a stoichiometric ratio in case **B**.
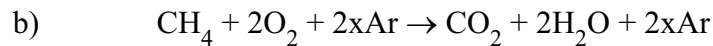
a)　　　　$CH_4 + vO_2 \rightarrow CO_2 + 2H_2O + (v - 2)O_2$
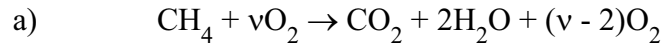
　　　$v_s = 2$ for stoichiometric mixture.

　　　$H_{P\ 3200} = H_R^\circ = H_P^\circ + \Delta H_{P\ 3200}$

　　　$\Delta \bar{h}_{CO2} = 33\ 579$ Btu/lbmol, $\Delta \bar{h}_{H2O} = 26\ 479$, $\Delta \bar{h}_{O2} = 21\ 860$

　　　$\Delta H_P = H_R^\circ - H_P^\circ = -H_{RP}^\circ = (50\ 010/2.326) \times 16.04 = 344\ 867$ Btu/lbmol

　　　　$= 33\ 579 + 2 \times 26\ 479 + (v - 2)21\ 860 = 42\ 817 + v \times 21\ 860$

　　　　$v = 13.8175$　　　$\Rightarrow$　　　$\phi = v_s/v = 2/13.8175 = \textbf{0.1447}$

b)　　　　$CH_4 + 2O_2 + 2xAr \rightarrow CO_2 + 2H_2O + 2xAr$
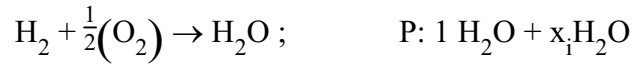
　　　$\Delta H_P = 33579 + 2 \times 26479 + 2 \times 0.1253 \times 39.948 \times (3200 - 536.67)$

　　　　$= 86537 + x \times 26662.5 = 344867 \Rightarrow \textbf{x = 9.689}$

14.133E

A closed, insulated container is charged with a stoichiometric ratio of oxygen and hydrogen at 77 F and 20 lbf/in.^{2}. After combustion, liquid water at 77 F is sprayed in such that the final temperature is 2100 R. What is the final pressure?

$$H_2 + \tfrac{1}{2}(O_2) \rightarrow H_2O \; ; \qquad P: 1\ H_2O + x_i H_2O$$

$$U_2 - U_1 = x_i \bar{h}_i = x_i \bar{h}^{\circ}_{f\ liq} = (1 + x_i)H_P - H_R - (1 + x_i)\bar{R}T_P + \tfrac{3}{2}\bar{R}T_R$$

table F.6: $H_R = \phi$, $H_P = -103\ 966 + 14\ 218.5 = -89\ 747.5$ Btu/lbmol,

Table F.11: $\bar{h}^{\circ}_{f\ liq} = -122\ 885$ Btu/lbmol

Substitute

$$x_i(-122885 + 89747.5 + 1.98588 \times 2100)$$

$$= -89747.5 - 1.98588(2100 - \tfrac{3}{2} \times 536.67) = -92319.2$$

$$x_i = 3.187$$

$$P_1V_1 = n_R\bar{R}T_1, \quad P_2V_2 = n_p\bar{R}T_p$$

$$\Rightarrow P_2 = \frac{P_1(1 + x_i)T_P}{1.5\ T_1} = \frac{20(4.187)(2100)}{1.5(536.67)} = \mathbf{218.5\ lbf/in^2}$$

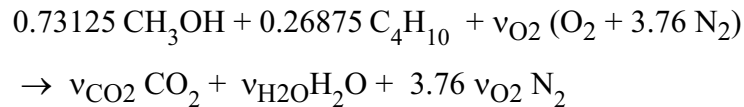**Enthalpy of combustion and heating value**

14.134E

A burner receives a mixture of two fuels with mass fraction 40% n-butane and 60% methanol both vapor. The fuel is burned with stoichiometric air. Find the product composition and the lower heating value of this fuel mixture (Btu/lbm fuel mix).

Since the fuel mixture is specified on a mass basis we need to find the mole fractions for the combustion equation. From Eq.12.4 we get

$$y_{butane} = (0.4/58.124) / [0.4/58.124 + 0.6/32.042] = 0.26875$$

$$y_{methanol} = 1 - y_{butane} = 0.73125$$

The reaction equation is

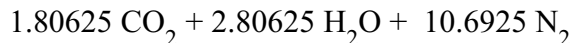$$0.73125 \, CH_3OH + 0.26875 \, C_4H_{10} + \nu_{O2} \, (O_2 + 3.76 \, N_2)$$

$$\rightarrow \nu_{CO2} \, CO_2 + \nu_{H2O} H_2O + 3.76 \, \nu_{O2} \, N_2$$

C balance: $0.73125 + 4 \times 0.26875 = \nu_{CO2} = 1.80625$

H$_2$ balance: $2 \times 0.73125 + 5 \times 0.26875 = \nu_{H2O} = 2.80625$

O balance: $0.73125 + 2 \, \nu_{O2} = 2 \, \nu_{CO2} + \nu_{H2O} = 6.41875 \implies \nu_{O2} = 2.84375$

   Now the products are:

$$1.80625 \, CO_2 + 2.80625 \, H_2O + 10.6925 \, N_2$$

Since the enthalpy of combustion is on a mass basis in table 14.3 (this is also the negative of the heating value) we get

LHV = $(0.4 \times 45\,714 + 0.6 \times 21\,093)/2.326$

   = **13 302 Btu/lbm fuel mixture**

Notice we took fuel vapor and water as vapor (lower heating value).

14.135E

Blast furnace gas in a steel mill is available at 500 F to be burned for the generation of steam. The composition of this gas is, on a volumetric basis,
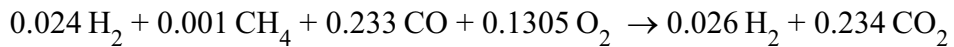
Component	CH_4	H_2	CO	CO_2	N_2	H_2O
Percent by volume	0.1	2.4	23.3	14.4	56.4	3.4

Find the lower heating value (Btu/ft^3) of this gas at 500 F and P_0.

Of the six components in the gas mixture, only the first 3 contribute to the heating value. These are, per lb mol of mixture:

$$0.024 \ H_2, \ 0.001 \ CH_4, \ 0.233 \ CO$$

For these components,

$$0.024 \ H_2 + 0.001 \ CH_4 + 0.233 \ CO + 0.1305 \ O_2 \rightarrow 0.026 \ H_2 + 0.234 \ CO_2$$

The remainder need not be included in the calculation, as the contributions to reactants and products cancel. For the lower HV(water vapor) at 500 F

$$\bar{h}_{RP} = 0.026(\text{-}103 \ 966 + 3488) + 0.234(\text{-}169 \ 184 + 4229) - 0.024(0 +$$
2101)

$$- \ 0.001(\text{-}32 \ 190 + 0.538 \times 16.04(500\text{-}77)) - 0.233(\text{-}47 \ 518 + 2981)$$

$$- \ 0.1305(0 + 3069) \ = \text{-}31 \ 257 \ Btu/lb \ mol \ fuel$$

$$\bar{v}_0 = \frac{\bar{R}T_0}{P_0} = \frac{1545 \times 536.7}{14.7 \times 144} = 391.47 \ ft^3/lb \ mol$$

$$LHV = 31 \ 680 / 391.47 = \textbf{79.85 Btu/ft}^3$$

Adiabatic flame temperature

14.136E

Hydrogen gas is burned with pure oxygen in a steady flow burner where both reactants are supplied in a stoichiometric ratio at the reference pressure and temperature. What is the adiabatic flame temperature?

The reaction equation is:

$$H_2 + \nu_{O2}\, O_2 \quad \Rightarrow \quad H_2O$$
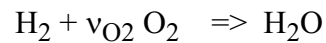
The balance of hydrogen is done, now for oxygen we need $\nu_{O2} = 0.5$.

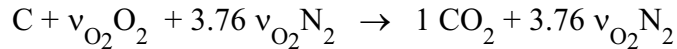Energy Eq.: $H_R = H_P \Rightarrow 0 = -103\,966 + \Delta\bar{h}_{H2O}$

$$\Rightarrow \quad \Delta\bar{h}_{H2O} = 103\,966 \text{ Btu/lbmol}$$

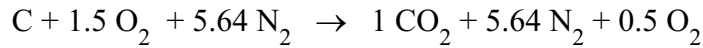Interpolate now in table F.6 for the temperature to give this enthalpy

T = 8985 R

14.137E

Carbon is burned with air in a furnace with 150% theoretical air and both reactants are supplied at the reference pressure and temperature. What is the adiabatic flame temperature?

$$C + \nu_{O_2}O_2 + 3.76\,\nu_{O_2}N_2 \;\rightarrow\; 1\,CO_2 + 3.76\,\nu_{O_2}N_2$$

From this we find $\nu_{O_2} = 1$ and the actual combustion reaction is

$$C + 1.5\,O_2 + 5.64\,N_2 \;\rightarrow\; 1\,CO_2 + 5.64\,N_2 + 0.5\,O_2$$

$$H_P = \overset{\circ}{H_P} + \Delta H_P = H_R = \overset{\circ}{H_R} \quad \Rightarrow$$

$$\Delta H_P = \overset{\circ}{H_R} - \overset{\circ}{H_P} = 0 - (-169\,184) = 169\,184 \text{ Btu/lbmol}$$

$$\Delta H_P = \Delta \bar{h}_{CO2} + 5.64\,\Delta \bar{h}_{N2} + 0.5\,\Delta \bar{h}_{O2}$$

Find T so ΔH_P takes on the required value. To start guessing assume all products are nitrogen (1 + 5.64 + 0.5 = 7.14) that gives $3400 < T < 3600$ R from Table F.6.

$$\Delta H_{P\,3400} = 36\,437 + 5.64 \times 22\,421 + 0.5 \times 23\,644 = 174\,713 \quad \text{too high}$$
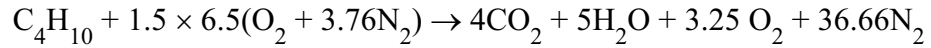
$$\Delta H_{P\,3200} = 33\,579 + 5.64 \times 20\,717 + 0.5 \times 21\,860 = 161\,353$$

Linear interpolation to find

$$T = 3200 + 200\,\frac{169\,184 - 161\,353}{174\,713 - 161\,353} = \textbf{3317 R}$$

14.138E

Butane gas at 77 F is mixed with 150% theoretical air at 1000 R and is burned in an adiabatic steady state combustor. What is the temperature of the products exiting the combustor?

$$C_4H_{10} + 1.5 \times 6.5(O_2 + 3.76N_2) \rightarrow 4CO_2 + 5H_2O + 3.25\,O_2 + 36.66N_2$$

$$H_R = H_R^\circ + \Delta H_{air,in}$$

$$H_P = H_P^\circ + 4\Delta\bar{h}_{CO_2} + 5\Delta\bar{h}_{H2O} + 3.25\Delta\bar{h}_{O_2} + 36.66\Delta\bar{h}_{N2}$$

$$H_P = H_R \implies \Delta H_P = H_R^\circ - H_P^\circ + \Delta H_{air,in}$$

$$\Delta H_P = -H_{RP}^\circ + \Delta H_{air,in} = \frac{45714}{2.326} \times 58.124 + 9.75 \times 3366 + 36.66 \times 3251$$

$$= 1\ 294\ 339 \text{ Btu/lbmol fuel}$$

$$= \left[4\Delta\bar{h}_{CO2} + 5\Delta\bar{h}_{H2O} + 3.25\Delta\bar{h}_{O2} + 36.66\Delta\bar{h}_{N2}\right] \text{ at } T_{ad}$$

Find the enthalpies from Table F.6

$$\Delta H_{P,3600R} = 1\ 281\ 185 \qquad \Delta H_{P,3800R} = 1\ 374\ 068 \text{ Btu/lbmol fuel}$$

$$\mathbf{T_{ad} = 3628 \ R}$$

14.139E

Liquid n-butane at T_0, is sprayed into a gas turbine with primary air flowing at 150 lbf/in.^{2}, 700 R in a stoichiometric ratio. After complete combustion, the products are at the adiabatic flame temperature, which is too high so secondary air at 150 lbf/in.^{2}, 700 R is added, with the resulting mixture being at 2500 R. Show that $T_{ad} > 2500$ R and find the ratio of secondary to primary air flow.

$$C_4H_{10} + 6.5 \, (O_2 + 3.76 \, N_2) \rightarrow \ 4 \, CO_2 + 5 \, H_2O + 24.44 \, N_2$$
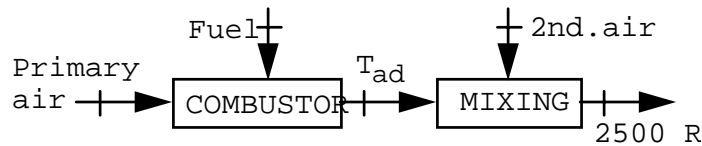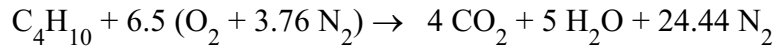
C.V. Combustor

$$H_R = H_{air} + H_{Fu} = H_P = H_P^\circ + \Delta H_P = H_R^\circ + \Delta H_R$$

$$\Delta H_P = H_R^\circ - H_P^\circ + \Delta H_R = -H_{RP}^\circ + \Delta H_R$$

$$= 45344 \times 58.124/2.326 + 6.5(1158 + 3.76 \times 1138)$$

$$= 1\ 168\ 433 \text{ Btu/lbmol fuel}$$

$$\Delta H_{P,2500R} = 4 \times 23755 + 5 \times 18478 + 24.44 \times 14855$$

$$= 550\ 466 \text{ Btu/lbmol fuel}$$

$$\Delta H_P > \Delta H_{P,2500R} \implies T_{ad} > 2500 \text{ R (If iteration } T_{ad} \cong 4400 \text{ R)}$$

C.V. Mixing chamber

$$\Delta H_P + \nu_{O2\ 2nd}\Delta H_{air,700} = \Delta H_{P,2500R} + \nu_{O2\ 2nd}\Delta H_{air,2500R}$$

$$\nu_{O2\ 2nd} = \frac{\Delta H_P - \Delta H_{P,2500}}{\Delta H_{air,2500} - \Delta H_{air,700}} = \frac{1168433 - 550466}{71571 - 5437} = 9.344$$

Ratio $= \nu_{O2\ 2nd}/\nu_{O2\ Prim.} = 9.344/6.5 = \mathbf{1.44}$

14.140E

Acetylene gas at 77 F, 14.7 lbf/in.^{2} is fed to the head of a cutting torch. Calculate the adiabatic flame temperature if the acetylene is burned with 100% theoretical air at 77 F. Repeat the answer for 100% theoretical oxygen at 77 F.

    a) $C_2H_2 + 2.5\,O_2 + 2.5 \times 3.76\,N_2 \rightarrow \quad 2\,CO_2 + 1\,H_2O + 9.4\,N_2$
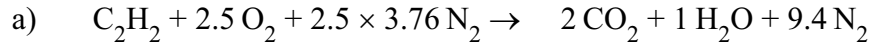
$H_R = \bar{h}^o_{f\,C_2H_2} = 97\,477$ Btu

$H_P = 2(-169\,184 + \Delta\bar{h}^*_{CO_2}) + 1(-103\,966 + \Delta\bar{h}^*_{H_2O}) + 9.4\,\Delta\bar{h}^*_{N_2}$

$Q_{CV} = H_P - H_R = 0$

$\Rightarrow \quad 2\,\Delta\bar{h}^*_{CO_2} + 1\,\Delta\bar{h}^*_{H_2O} + 9.4\,\Delta\bar{h}^*_{N_2} = 539\,811$ Btu/lbmol

Trial and Error: $T_{PROD} = $ **5236 R**

    $2 \times 147\,196 + 121\,488 + 9.4 \times 89\,348 = 1\,255\,751$ **OK**

    b) $C_2H_2 + 2.5\,O_2 \rightarrow \quad 2\,CO_2 + H_2O$
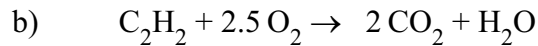
$H_R = 97\,477$ Btu

$H_P = 2(-169\,184 + \Delta\bar{h}^*_{CO2}) + 1(-103\,966 + \Delta\bar{h}^*_{H2O})$

$\Rightarrow \quad 2\,\Delta\bar{h}^*_{CO2} + 1\,\Delta\bar{h}^*_{H2O} = 539\,811$

At 10 000 R (limit of F.6): $2 \times 135\,426 + 118\,440 = 389\,292$

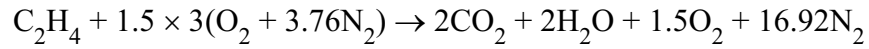At 9500 R: $2 \times 127\,734 + 111\,289 = 366\,757$

    or 4507/100 R change,   Difference, extrapolating

$T_{PROD} \approx 10\,000 + \dfrac{150519}{45.07} \approx$ **13 340 R**
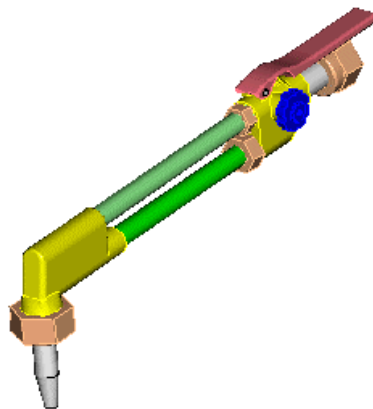
14.141E

Ethene, C_2H_4, burns with 150% theoretical air in a steady flow constant-pressure process with reactants entering at P_0, T_0. Find the adiabatic flame temperature.

$$C_2H_4 + 1.5 \times 3(O_2 + 3.76N_2) \rightarrow 2CO_2 + 2H_2O + 1.5O_2 + 16.92N_2$$

$$H_P = H_R = H_P^\circ + \Delta H_P = H_R^\circ \Rightarrow$$

$$\Delta H_P = H_R^\circ - H_P^\circ = -H_{RP}^\circ = 28.054 \times 47\ 158/2.326 = 568\ 775 \text{ Btu/lbmol}$$

$$\Delta H_P = 2\Delta\bar{h}_{CO2} + 2\Delta\bar{h}_{H2O} + 1.5\Delta\bar{h}_{O2} + 16.92\Delta\bar{h}_{N2}$$

Trial and error on T_{ad}.

$$\Delta H_{P,3400R} = 545\ 437, \quad \Delta H_{P,3600R} = 587\ 736 \text{ Btu/lbmol}$$

$$\mathbf{T_{ad} = 3510\ R}$$

14.142E

Solid carbon is burned with stoichiometric air in a steady state process, as shown in Fig. P14.39. The reactants at T_0, P_0 are heated in a preheater to $T_2 = 900$ R with the energy given by the products before flowing to a second heat exchanger, which they leave at T_0. Find the temperature of the products T_4, and the heat transfer per lb mol of fuel (4 to 5) in the second heat exchanger.

    a) Following the flow we have: Inlet T_1, after preheater T_2, after mixing and combustion chamber T_3, after preheater T_4, after last heat exchanger $T_5 = T_1$.

    b) Products out of preheater T_4. Control volume: Total minus last heat exchanger.

$$C + O_2 + 3.76\ N_2 \rightarrow CO_2 + 3.76\ N_2$$
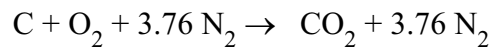
Energy Eq.:

$$H_R = H_R^\circ = H_{P_3} = H_P^\circ + \Delta H_{P_3} = \bar{h}_{f\,CO_2}^\circ + \Delta \bar{h}_{CO_2} + 3.76\Delta\bar{h}_{N2}$$

$$\bar{h}_{f\,CO_2}^\circ = \text{-169 184}, \quad \Delta H_{P_3\ 4400} = 167\ 764, \quad \Delta H_{P_3\ 4600} = 177\ 277$$

$$\Rightarrow T_3 = T_{ad.flame} = \textbf{4430 R}$$

    c) Control volume total. Then energy equation:

$$H_R^\circ + \bar{q} = H_P^\circ$$

$$\bar{q} = H_{RP}^\circ = \bar{h}_{f\,CO_2}^\circ - 0 = \textbf{-169 184 } \frac{\textbf{Btu}}{\textbf{lbmol fuel}}$$

Second law for the combustion process

14.143E

   Methane is burned with air both supplied at the reference conditions. There is enough excess air to give a flame temperature of 3200 R. What are the percent theoretical air and the irreversibility in the process?

   The combustion equation with X times theoretical air is
   $$CH_4 + 2X(O_2 + 3.76\ N_2) \rightarrow CO_2 + 2H_2O + 2(X-1)O_2 + 7.52X\ N_2$$
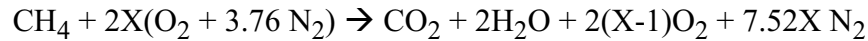
   Energy Eq.: $H_{air} + H_{fuel} = H_R = H_P = \overset{\circ}{H_P} + \Delta H_P = \overset{\circ}{H_R} + \Delta H_R$

   $\Rightarrow \quad \Delta H_P = \overset{\circ}{H_R} + \Delta H_R - \overset{\circ}{H_P} = -\overset{\circ}{H_{RP}} + 0$

   From Table 14.3: $-\overset{\circ}{H_{RP}} = -16.04\ (-50\ 010)/2.326 = 344\ 867$ Btu/lbmol

   $$\Delta H_P = \Delta \bar{h}^*_{CO2} + 2\ \Delta \bar{h}^*_{H2O} + 2(X-1)\ \Delta \bar{h}^*_{O2} + 7.52X\ \Delta \bar{h}^*_{N2}$$

   From Table F.6 and the energy equation
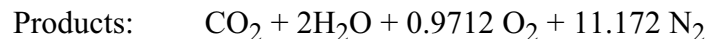
   $\Delta H_{P\ 3200} = 33\ 579 + 2 \times 26\ 479 + 2(X-1)\ 21\ 860 + 7.52X \times 20\ 717 = 344\ 867$

   so

   $$42\ 817 + 199\ 512\ X = 344\ 867 \quad \Rightarrow \quad X = 1.514$$
   $$\%\text{Theoretical air} = \mathbf{151.4\%}$$

   The products are

   Products: $CO_2 + 2H_2O + 0.9712\ O_2 + 11.172\ N_2$

   The second law
   $$S_{gen} = S_P - S_R \quad \text{and} \quad I = T_o\ S_{gen}$$

   Reactants: $P_i = 14.7$ psia, $P_O = 14.7$ psia, $\bar{s}^o_f$ from Table F.6 and F.11

	n_i	y_i	$\bar{s}^o_f$	$-\bar{R}\ ln\ \dfrac{y_iP_i}{P_o}$	$\bar{S}_i\ \dfrac{Btu}{lbmol\ R}$
CH_4	1	1	44.459	0	44.459
O_2	2X	0.21	48.973	3.099	52.072
N_2	7.52 X	0.79	45.739	0.468	46.207

$$S_R = \sum n_i \bar{S}_i = 728.21 \text{ Btu/R lbmol fuel}$$

Products: $P_e = 14.7$ psia, $P_o = 14.7$ psia, From Table F.6

|	n_i	y_i	$\bar{s}^o_{3200}$	$-\bar{R} \ln \dfrac{y_i P_e}{P_o}$	$\bar{S}_i \dfrac{Btu}{lbmol\ R}$
CO_2	1	0.06604	72.160	5.3966	77.557
H_2O	2	0.13208	61.796	4.0201	65.816
O_2	0.9712	0.06413	61.109	5.4549	66.564
N_2	11.172	0.73775	59.175	0.6040	59.779

$S_P = \sum n_i \bar{S}_i = 941.69$ Btu/R lbmol fuel;

$I = T_o(S_P - S_R) = 536.67(941.69 - 728.21) = \textbf{114 568 Btu/lbmol fuel}$

14.144E

Two pound moles of ammonia are burned in a steady state process with x lb mol of oxygen. The products, consisting of H_2O, N_2, and the excess O_2, exit at 400 F, 1000 lbf/in.^{2}.
a. Calculate x if half the water in the products is condensed.
b. Calculate the absolute entropy of the products at the exit conditions.

$$2NH_3 + xO_2 \rightarrow 3H_2O + N_2 + (x - 1.5)O_2$$
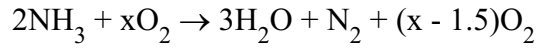
Products at 400 F, 1000 lbf/in^2 with $n_{H2O\ LIQ} = n_{H2O\ VAP} = 1.5$

a) $y_{H2O\ VAP} = \dfrac{P_G}{P} = \dfrac{247.1}{1000} = \dfrac{1.5}{1.5 + 1 + x - 1.5}$

   $x = \mathbf{5.070}$

b) $S_{PROD} = S_{GAS\ MIX} + S_{H2O\ LIQ}$

   Gas mixture:

|	n_i	y_i	$\bar{s}_i^\circ$	$-\bar{R}\ln\dfrac{y_iP}{P_0}$	$\bar{S}_i$
H_2O	1.5	0.2471	48.939	-5.604	43.335
O_2	3.57	0.5881	52.366	-7.326	45.040
N_2	1.0	0.1648	49.049	-4.800	44.249

$S_{GAS\ MIX} = 1.5(43.335) + 3.57(45.040) + 1.0(44.249) = 270.04$ Btu/R

$S_{H2O\ LIQ} = 1.5[16.707 + 18.015(0.5647 - 0.0877)] = 37.95$ Btu/R

$S_{PROD} = 270.04 + 37.95 = \mathbf{307.99\ Btu/R}$

14.145E

Graphite, C, at P_0, T_0 is burned with air coming in at P_0, 900 R in a ratio so the products exit at P_0, 2200 R. Find the equivalence ratio, the percent theoretical air and the total irreversibility.

$$C + x(O_2 + 3.76N_2) \rightarrow CO_2 + (x - 1)O_2 + 3.76 \, x \, N_2$$
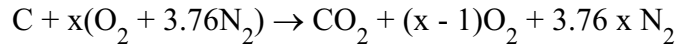
$$H_P = H_R \Rightarrow \Delta H_{P,2200} - \Delta H_R = H_R^\circ - H_P^\circ = -H_{RP}^\circ$$

$$19659 + (x - 1)13136 + 3.76 \times x \times 12407 - x(2616 + 3.76 \times 2541)$$
$$= 0 - (-169184)$$

$$\Rightarrow 6523 + x \times 47616.2 = 169184 \quad \Rightarrow \quad x = 3.416,$$

or **342 % theoretical air**

Equivalence ratio $\phi = 1/x = $ **0.293**

$$S_{gen} = s_P - s_R = \sum_P v_i(s_i^\circ - \bar{R}\ln y_i) - \sum_R v_i(s_i^\circ - \bar{R}\ln y_i)$$

R: $y_{O_2} = 0.21$ $\quad\quad y_{N2} = 0.79$

P: $y_{O_2} = 0.1507$ $\quad\quad\quad y_{N2} = 0.79$ $\quad\quad\quad y_{CO2} = 0.0593$

$$S_{gen} = 66.952 + 5.610 + 2.416(59.844 + 3.758)$$

$$+ 3.76 \times 3.416(56.066 + 0.468) - 1.371$$

$$- 3.416(52.686 + 3.099 + 3.76(49.353 + 0.468))$$

$$= 120.5 \text{ Btu/(lbmol C} \times \text{R)}$$

$$I = T_0 S_{gen} = \textbf{64 677 Btu/lbmol C}$$

14.146E

Repeat problem 14.127E, but assume that saturated-liquid oxygen at 170 R is used instead of 77 F oxygen gas in the combustion process. Use the generalized charts to determine the properties of liquid oxygen.

Problem the same as 14.127E, except oxygen enters at 2 as saturated liquid at 170 R.

At 170 R, $T_{r2} = \dfrac{170}{278.6} = 0.61 \Rightarrow \Delta\bar{h}_f = 5.1$

From Fig. D.2:

$(\bar{h}^* - \bar{h}) = 1.98589 \times 278.6 \times 5.1 = 2822$ Btu/lbmol

$\Delta H_{P_3} = \overset{\circ}{H_R} + \Delta H_R - \overset{\circ}{H_P} + Q_{CV} = 21647 - 0.5(2822)$

$\qquad + 0.5(0.219)(170 - 536.67)(32) + 103\ 966 - 1442 = 121\ 475$

With $\Delta H_{P3\ 5000\ R} = 120\ 071, \quad \Delta H_{P3\ 5200\ R} = 126\ 224$

$\qquad \Rightarrow T_3 = \mathbf{5045\ R}$

14.147E

Hydrogen peroxide, H_2O_2, enters a gas generator at 77 F, 75 lbf/in.^{2} at the rate of 0.2 lbm/s and is decomposed to steam and oxygen exiting at 1500 R, 75 lbf/in.^{2}. The resulting mixture is expanded through a turbine to atmospheric pressure, 14.7 lbf/in.^{2}, as shown in Fig. P14.98. Determine the power output of the turbine, and the heat transfer rate in the gas generator. The enthalpy of formation of liquid H_2O_2 is -80541 Btu/lb mol.

$$H_2O_2 \rightarrow H_2O + \tfrac{1}{2}O_2$$
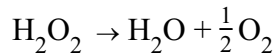
$$\dot{n}_{Fu} = \dot{m}_{Fu}/M_{Fu} = 0.2/34.015 = 0.00588 \text{ lbmol/s}$$

$$\dot{n}_{ex,mix} = 1.5 \times \dot{n}_{Fu} = 0.00882 \text{ lbmol/s}$$

$$\bar{C}_{p\,mix} = \tfrac{2}{3} \times 0.445 \times 18.015 + \tfrac{1}{3} \times 0.219 \times 31.999 = 7.6804$$

$$\bar{C}_{v\,mix} = \bar{C}_{p\,mix} - 1.98588 = 5.6945 \quad ; \quad k_{mix} = \bar{C}_{p\,mix}/\bar{C}_{v\,mix} = 1.3487$$

Reversible turbine

$$T_3 = T_2 \times (P_3/P_2)^{(k-1)/k} = 1500 \times (14.7/75)^{0.2585} = 984.3 \text{ R}$$

$$\bar{w} = \bar{C}_p(T_2 - T_3) = 7.6804(1500 - 984.3) = 3960.8 \text{ Btu/lbmol}$$
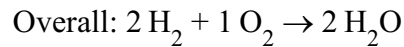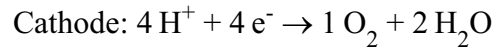
$$\dot{W}_{CV} = \dot{n}_{mix} \times \bar{w} = 0.00882 \times 3960.8 = \textbf{34.9 Btu/s}$$

C.V. Gas generator

$$\dot{Q}_{CV} = \dot{H}_2 - \dot{H}_1 = 0.00588 \times (-103\,966 + 8306) + 0.00294(7297.5)$$
$$- 0.00588(-80\,541) = \textbf{-67.45 Btu/s}$$

Fuel Cells, Efficiency, and Review

14.148E

In Example 14.16, a basic hydrogen–oxygen fuel cell reaction was analyzed at 25°C, 100 kPa. Repeat this calculation, assuming that the fuel cell operates on air at 77 F, 14.7 lbf/in.^{2}, instead of on pure oxygen at this state.

Anode: $2\,H_2 \rightarrow 4\,e^- + 4\,H^+$

Cathode: $4\,H^+ + 4\,e^- \rightarrow 1\,O_2 + 2\,H_2O$

Overall: $2\,H_2 + 1\,O_2 \rightarrow 2\,H_2O$

Example $\boxed{14.16}$: $\Delta G_{25°C}$ = -474 283 kJ/kmol

$\qquad\qquad$ Or $\Delta G_{77\,F}$ = -203 904 Btu/lbmol

$P_{O_2} = y_{O2} \times P = 0.21 \times 14.7 = 3.087$ lbf/in^2

$\bar{s}_{O_2} = 48.973 - 1.98589 \ln 0.21 = 52.072$

$\Delta S = 2(16.707) - 2(31.186) - 1(52.072) = -81.03$ Btu/R

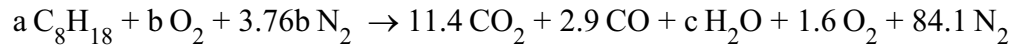$\Delta H = 2(-122\,885) - 2(0) - 1(0) = -245\,770$ Btu/lbmol

$\Delta G_{77\,F} = -245\,770 - 536.67(-81.03) = 202\,284$ Btu/lbmol

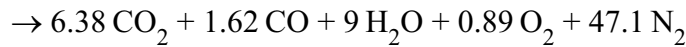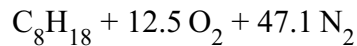$E° = -\Delta G/N_0 e\,n_e = 202\,284 \times 2.326/(96\,485 \times 4) = $ **1.219 V**

14.149E

A small air-cooled gasoline engine is tested, and the output is found to be 2.0 hp. The temperature of the products is measured and found to be 730 F. The products are analyzed on a dry volumetric basis, with the following result 11.4% CO_2, 2.9% CO, 1.6% O_2 and 84.1% N_2. The fuel may be considered to be liquid octane. The fuel and air enter the engine at 77 F, and the flow rate of fuel to the engine is 1.8 lbm/h. Determine the rate of heat transfer from the engine and its thermal efficiency.

$$a\,C_8H_{18} + b\,O_2 + 3.76b\,N_2 \rightarrow 11.4\,CO_2 + 2.9\,CO + c\,H_2O + 1.6\,O_2 + 84.1\,N_2$$

$$b = 84.1/3.76 = 22.37, \quad a = (1/8)(11.4 + 2.9) = 1.788, \quad c = 9a = 16.088$$

$$C_8H_{18} + 12.5\,O_2 + 47.1\,N_2$$

$$\rightarrow 6.38\,CO_2 + 1.62\,CO + 9\,H_2O + 0.89\,O_2 + 47.1\,N_2$$

a) $H_R = \bar{h}^{\circ}_{f\,C8H18} = -107\,526$ Btu/lbmol

$\quad H_P = 6.38(-169\,184 + 6807) + 1.62(-47\,518 + 4647)$

$\qquad + 9(-103\,966 + 5475) + 0.89(0+4822)$

$\qquad + 47.1(0 + 4617) = -1\,770\,092$ Btu/lbmol

$\quad H_P - H_R = -1\,770\,092 - (-107\,526) = -1\,662\,566$ Btu/lbmol

$$\dot{H}_P - \dot{H}_R = \frac{1.8}{114.23}(-1\,662\,566) = -26\,198 \text{ Btu/h}$$

$$\dot{Q}_{CV} = -26\,198 + 2.0\,(2544) = \textbf{-21 110 Btu/h}$$

b) Fuel heating value from table 14.3 converted to Btu/lbm

$$\dot{Q}_H = 1.8 \times (47\,893/2.326) = 37\,062 \text{ Btu/h}$$

$$\dot{W}_{NET} = 2.0 \times 2544 = 5088 \text{ Btu/h}; \quad \eta_{TH} = \frac{5088}{37062} = \textbf{0.137}$$

14.150E

A gasoline engine uses liquid octane and air, both supplied at P_o, T_o, in a stoichiometric ratio. The products (complete combustion) flow out of the exhaust valve at 2000 R. Assume that the heat loss carried away by the cooling water, at 200 F, is equal to the work output. Find the efficiency of the engine expressed as (work/lower heating value) and the second law efficiency.

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$
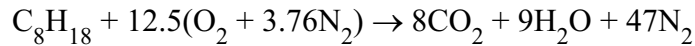
LHV = 44 425 × 114.232/2.326 = 2 181 753 Btu/lbmol fuel

$\Delta H_{P,2000}$ = 8 × 16 982 + 9 × 13 183 + 47 × 10 804 = 643 470

C.V. Total engine: $H_{in} = H_{ex} + W + Q_{loss} = H_{ex} + 2W$

$$W = (H_{in} - H_{ex})/2 = (H_R - H_P)/2 = (-H^o_{RP} - \Delta H_{P,2000})/2$$

$$= (2\ 181\ 753 - 643\ 470)/2 = 769\ 142 \text{ Btu/lbmol fuel}$$

η_{TH} = W/LHV = 769 142/2 181 753 = **0.353**

For 2nd law efficiency we must find reversible work

$$\bar{S}_{in} = \bar{s}_{fuel} + 12.5(\bar{s}_{O_2} + 3.76\bar{s}_{N_2})$$

$$= 86.122 + 12.5\left[48.973 - 1.98589 \ln (1/4.76)\right]$$

$$+ 47\left[45.739 - 1.98589 \ln (3.76/4.76)\right]$$

$$= 2908.8 \text{ Btu/(lbmol fuel} \times \text{R)}$$

$$\bar{S}_{ex} = 8\bar{s}_{CO2} + 9\bar{s}_{H2O} + 47\bar{s}_{N2} = 8\left[65.677 - 1.98589 \ln (8/64)\right]$$

$$+ 9\left[56.619 - 1.98589 \ln \left(\frac{9}{64}\right)\right] + 47\left[55.302 - 1.98589 \ln \left(\frac{47}{64}\right)\right]$$

$$= 3731.1 \text{ Btu/(lbmol fuel} \times \text{R)}$$

Assume the same Q_{loss} out to 200 F = 659.67 R reservoir and compute Q_0^{rev}:

$$\bar{S}_{in} + Q_0^{rev}/T_0 = \bar{S}_{ex} + Q_{loss}/T_{res}$$

$$Q_0^{rev} = T_0(\bar{S}_{ex} - \bar{S}_{in}) + Q_{loss}T_0/T_{res}$$

$$= 536.67(3731.1 - 2908.8) + 769\ 142*536.67/659.67$$

$$= 1\ 067\ 034 \text{ Btu/lbmol fuel}$$

$$W^{rev} = H_{in} - H_{ex} - Q_{loss} + Q_0^{rev} = W_{ac} + Q_0^{rev}$$

$$= 769\ 142 + 1\ 067\ 034 = 1\ 836\ 176$$

$\eta_{II} = W_{ac}/W^{rev} = 769\ 142/1\ 836\ 176 = **0.419**$

14.151E

Ethene, C_2H_4, and propane, C_3H_8, in a 1:1 mole ratio as gases are burned with 120% theoretical air in a gas turbine. Fuel is added at 77 F, 150 lbf/in.^{2} and the air comes from the atmosphere, 77 F, 15 lbf/in.^{2} through a compressor to 150 lbf/in.^{2} and mixed with the fuel. The turbine work is such that the exit temperature is 1500 R with an exit pressure of 14.7 lbf/in.^{2}. Find the mixture temperature before combustion, and also the work, assuming an adiabatic turbine.

$$C_2H_4 + C_3H_8 + v_{O2}(O_2 + 3.76N_2) \rightarrow 5CO_2 + 6H_2O + v_{N2}N_2$$
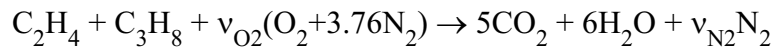
$$\phi = 1 \Rightarrow \quad v_{O2} = 8 \quad \phi = 1/1.2 \quad \Rightarrow \quad v_{O2} = 9.6$$

so we have 45.696 lbmol air per 2 lbmol fuel

$$C_2H_4 + C_3H_8 + 9.6(O_2 + 3.76N_2) \rightarrow 5CO_2 + 6H_2O + 1.6\,O_2 + 36.096N_2$$
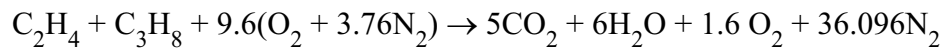
C.V. Compressor (air flow)

$$w_{c,in} = h_2 - h_1 \quad s_2 = s_1 \Rightarrow P_{r1} = 1.0907$$

$$P_{r2} = P_{r1}P_2/P_1 = 10.907 \Rightarrow T_{2\,air} = 1027.3\ R$$

$$w_{c,in} = 247.81 - 128.38 = 119.53\ \text{Btu/lbm} = 3462.4\ \text{Btu/lbmol air}$$

C.V. Mixing chamber

$$\dot{n}_{air}\bar{h}_{air\,in} + \dot{n}_{fu1}\bar{h}_{fu1} + \dot{n}_{fu2}\bar{h}_{fu2} = (\text{same})_{exit}$$

$$(\bar{C}_{PF1} + \bar{C}_{PF2})(T_{ex} - T_0) = 45.696\,\bar{C}_{P\,air}(T_{2\,air} - T_{ex})$$

$$\bar{C}_{PF1} = 11.53, \quad \bar{C}_{PF2} = 17.95, \quad \bar{C}_{P\,air} = 6.953$$

$$T_{ex} = \frac{45.696\bar{C}_{P\,air}T_2 + (\bar{C}_{PF1} + \bar{C}_{PF2})T_0}{\bar{C}_{PF1} + \bar{C}_{PF2} + 45.696\bar{C}_{air}} = \mathbf{985.6\ R} = T_{in\,combust}$$

Turbine work: take C.V. total and subtract compressor work.

$$W_{total} = H_{in} - H_{out} = H_R - H_{P,1500}$$

$$= \bar{h}^\circ_{f\,F1} + \bar{h}^\circ_{f\,F2} - 5\bar{h}_{CO2} - 6\bar{h}_{H2O} - 36.096\bar{h}_{N2} - 1.6\bar{h}_{O2}$$

$$= 22557 + (-44669) - 5(10557 - 169184)$$

$$- 6(8306 - 103966) - 36.096 \times 6925 - 1.6 \times 7297.5$$

$$= 1\,083\,342\ \text{Btu/2 lbmol Fuel}$$

$$w_T = w_{tot} + w_{c,in} = 1\,083\,342 + 3462.4 \times 45.696$$

$$= \mathbf{1\,241\,560\ Btu/2\ lbmol\ fuel}$$