MCG2131 Midterm 2015 - Solutions

Version A

1. (a) $p_V = \varphi P_{SAT}$, $P_{SAT} = 2.339$ kPa, $p_V = 1.1695$ kPa , and $\omega_1 = 0.00729$ kg/kg dry air

By interpolation in the steam table, $T_{DP} = 9.2°C$.

(b) $m_a = V p_{a1} / R_a T_1$ and $p_a = P - p_V$, so that $m_a = 11.87$ kg dry air/s

(c) Since water condenses, final state is saturated, and by definition $\varphi_2 = 100\%$

then $p_{V2} = P_{SAT} = 7.384$ kPa and $\omega_2 = 0.00463$ kg/kg dry air

water balance: $m_a \omega_1 = m_a \omega_2 + m_W$, from which $m_W = 0.0316$ kg/s

(d) steady flow first law, neglect PE and KE:

$Q + m_a h_{A1} = W + m_a h_{A2} + m_W h_f$

$h_{A1} = c_{Pa} (T - T_{REF}) + \omega_1 h_g = 58.65$ kJ/kg dry air ($h_g = 2538.1$ kJ/kg)

$h_{A2} = 72.15$ kJ/kg dry air ($h_g = 2574.3$ kJ/kg)

$h_f = 167.57$ kJ/kg

and $Q = -134$ kW (note that W is negative!)

2. (a) Stoichiometric combustion:

$$(0.50/12\ C + 0.06/1\ H + 0.44/16\ O + 0.25/18\ H_2O) + b\ (O_2 + 3.762\ N_2) \rightarrow$$

$$c\ CO_2 + d\ H_2O + e\ CO + f\ O_2 + g\ N_2$$

- for stoichiometric combustion, e = f = 0

- balances give c = 0.04167, d = 0.04389, and b_{STOICH} = 0.04292 kmol/kg dry fuel

(b) Actual combustion: $b = 1.30\ b_{STOICH}$

Re-balance equation, again with a = 1 kg. Coefficient e is still = 0, since no information is given on CO.

c = 0.04167, d = 0.04389, f = 0.01287, and g = 0.20989 kmol / kg dry fuel

(c) Energy balance with HHV:

$$Q + m_{FUEL}\ HHV + \Sigma\ (n_i\ \Delta h_i)_{REACTANTS} = \Sigma\ (n_i\ \Delta h_i)_{PRODUCTS} + n_{H2O\ VAP}\ h_{fg}$$

$\Sigma_{REACTANTS}$ = 0 (25 °C) ; $\Sigma_{PRODUCTS}$ = 980.8 kJ/kg dry fuel

Q = - 17.09 MJ/kg dry fuel, $\eta = |Q| / HHV = 85.4\%$

(d) $V = (\Sigma n_{i\,PROD})\,\bar{R}\,T_{PROD}/P$ = 10.15 m^3 / kg dry fuel

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Version B

1. (a) Stoichiometric combustion:

$$(0.52/12\ C + 0.06/1\ H + 0.42/16\ O + 0.30/18\ H_2O) + b\ (O_2 + 3.762\ N_2) \rightarrow$$

$$c\ CO_2 + d\ H_2O + e\ CO + f\ O_2 + g\ N_2$$

- for stoichiometric combustion, e = f = 0

- balances give c = 0.04333, d = 0.04667, and b_{STOICH} = 0.04521 kmol/kg dry fuel

(b) Actual combustion: b = 1.35 b_{STOICH} = 0.06103 kmol/kg dry fuel

Re-balance equation, again with a = 1 kg. Coefficient e is still = 0, since no information is given on CO.

c = 0.04333, d = 0.04667, f = 0.0158, and g = 0.2296 kmol / kg dry fuel

(c) Energy balance with HHV:

$$Q + m_{FUEL}\ HHV + \Sigma\ (n_i\ \Delta h_i)_{REACTANTS} = \Sigma\ (n_i\ \Delta h_i)_{PRODUCTS} + n_{H2O\ VAP}\ h_{fg}$$

$\Sigma_{REACTANTS}$ = 0 (25 °C) ; $\Sigma_{PRODUCTS}$ = 2136.4 kJ/kg dry fuel

Q = - 16.81 MJ/kg dry fuel, $\eta = |Q| / HHV = 80.05\%$

(d) $V = (\Sigma n_{i\,PROD})\,\bar{R}\,T_{PROD}/P$ = 13.81 m^3 / kg dry fuel

2. (a) $p_V = \varphi P_{SAT}$, $P_{SAT} = 3.169$ kPa, $p_V = 1.2676$ kPa , and $\omega_1 = 0.00791$ kg/kg dry air

By interpolation in the steam table, $T_{DP} = 10.4°C$.

(b) $m_a = V p_{a1} / R_a T_1$ and $p_a = P - p_V$, so that $m_a = 58.3$ kg dry air/s

(c) Since water condenses, final state is saturated, and by definition $\varphi_2 = 100\%$

then $p_{V2} = P_{SAT} = 7.384$ kPa and $\omega_2 = 0.00579$ kg/kg dry air

water balance: $m_a \omega_1 = m_a \omega_2 + m_W$, from which $m_W = 0.1231$ kg/s

(d) steady flow first law, neglect PE and KE:

$Q + m_a h_{A1} = W + m_a h_{A2} + m_W h_f$

$h_{A1} = c_{Pa} (T - T_{REF}) + \omega_1 h_g = 65.32$ kJ/kg dry air ($h_g = 2547.2$ kJ/kg)

$h_{A2} = 75.16$ kJ/kg dry air ($h_g = 2574.3$ kJ/kg)

$h_f = 167.57$ kJ/kg

and $Q = - 606$ kW (note that W is negative!)

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Version C

1. (a) $p_V = \varphi P_{SAT}$, $P_{SAT} = 1.705$ kPa, $p_V = 1.023$ kPa , and $\omega_1 = 0.00636$ kg/kg dry air

By interpolation in the steam table, $T_{DP} = 7.1\,^\circ$C.

(b) Since water condenses, final state is saturated, and by definition $\varphi_2 = 100\%$

then $p_{V2} = P_{SAT} = 7.384$ kPa and $\omega_2 = 0.00385$ kg/kg dry air

water balance: $m_a\,\omega_1 = m_a\,\omega_2 + m_W$, from which $m_W = 0.0152$ kg/s

(c) $m_a = V\,p_{a1} / R_a\,T_1$ and $p_a = P - p_V$, so that $m_a = 6.046$ kg dry air/s

(d) steady flow first law, neglect PE and KE:

$Q + m_a\,h_{A1} = W + m_a\,h_{A2} + m_W\,h_f$

$h_{A1} = c_{Pa}\,(T - T_{REF}) + \omega_1\,h_g = 51.24$ kJ/kg dry air ($h_g = 2528.9$ kJ/kg)

$h_{A2} = 70.15$ kJ/kg dry air ($h_g = 2574.3$ kJ/kg)

$h_f = 167.57$ kJ/kg

and $Q = -33.1$ kW (note that W is negative!)

2. (a) Stoichiometric combustion:

$$(0.50/12\ C + 0.07/1\ H + 0.43/16\ O + 0.20/18\ H_2O) + b\ (O_2 + 3.762\ N_2) \rightarrow$$

$$c\ CO_2 + d\ H_2O + e\ CO + f\ O_2 + g\ N_2$$

- for stoichiometric combustion, e = f = 0

- balances give c = 0.04167, d = 0.04611, and b_{STOICH} = 0.04573 kmol/kg dry fuel

(b) Actual combustion: b = 1.30 b_{STOICH} = 0.05716 kmol/kg dry fuel

Re-balance equation, again with a = 1 kg. Coefficient e is still = 0, since no information is given on CO.

c = 0.04167, d = 0.04611, f = 0.01143, and g = 0.2150 kmol / kg dry fuel

(c) Energy balance with HHV:

$$Q + m_{FUEL}\ HHV + \Sigma\ (n_i\ \Delta h_i)_{REACTANTS} = \Sigma\ (n_i\ \Delta h_i)_{PRODUCTS} + n_{H2O\ VAP}\ h_{fg}$$

$\Sigma_{REACTANTS}$ = 0 (25°C) ; $\Sigma_{PRODUCTS}$ = 2005.9 kJ/kg dry fuel

Q = - 15.97 MJ/kg dry fuel, $\eta = |Q| / HHV = 79.8\%$

(d) $V = (\Sigma n_{i\,PROD})\,\bar{R}\,T_{PROD}/P$ = 12.93 m^3 / kg dry fuel