**15-73** A high efficiency gas furnace burns gaseous propane C_3H_8 with 140 percent theoretical air. The volume flow rate of water condensed from the product gases is to be determined.

Assumptions **1** Combustion is complete. **2** The combustion products contain CO_2, H_2O, O_2, and N_2 only.

Properties The molar masses of C, H_2, O_2 and air are 12 kg/kmol, 2 kg/kmol, 32 kg/kmol, and 29 kg/kmol, respectively (Table A-1).

Analysis The reaction equation for 40% excess air (140% theoretical air) is

$$C_3H_8 + 1.4a_{th}[O_2 + 3.76N_2] \longrightarrow B\,CO_2 + D\,H_2O + E\,O_2 + F\,N_2$$
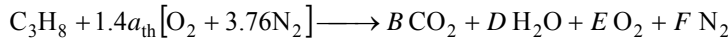
where a_{th} is the stoichiometric coefficient for air. We have automatically accounted for the 40% excess air by using the factor $1.4a_{th}$ instead of a_{th} for air. The coefficient a_{th} and other coefficients are to be determined from the mass balances
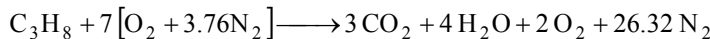
Carbon balance: $B = 3$

Hydrogen balance: $2D = 8 \longrightarrow D = 4$

Oxygen balance: $2 \times 1.4a_{th} = 2B + D + 2E$

$$0.4a_{th} = E$$

Nitrogen balance: $1.4a_{th} \times 3.76 = F$

Solving the above equations, we find the coefficients ($E = 2$, $F = 26.32$, and $a_{th} = 5$) and write the balanced reaction equation as

$$C_3H_8 + 7[O_2 + 3.76N_2] \longrightarrow 3\,CO_2 + 4\,H_2O + 2\,O_2 + 26.32\,N_2$$

The partial pressure of water in the saturated product mixture at the dew point is

$$P_{v,prod} = P_{sat@40°C} = 7.3851\,kPa$$

The vapor mole fraction is

$$y_v = \frac{P_{v,prod}}{P_{prod}} = \frac{7.3851\,kPa}{100\,kPa} = 0.07385$$

The kmoles of water condensed is determined from

$$y_v = \frac{N_{water}}{N_{total,product}} \longrightarrow 0.07385 = \frac{4 - N_w}{3 + 4 - N_w + 2 + 26.32} \longrightarrow N_w = 1.503\,kmol$$

The steady-flow energy balance is expressed as

$$\dot{N}_{fuel}H_R = \dot{Q}_{fuel} + \dot{N}_{fuel}H_P$$

where $\quad \dot{Q}_{fuel} = \dfrac{\dot{Q}_{out}}{\eta_{furnace}} = \dfrac{31,650\,kJ/h}{0.96} = 32,969\,kJ/h$

$$H_R = \bar{h}_f^{\,o}{}_{fuel@25°C} + 7\bar{h}_{O2@25°C} + 26.32\bar{h}_{N2@25°C}$$

$$= (-103,847\,kJ/kmol) + 7(0) + 26.32(0) = -103,847\,kJ/kmol$$

$$H_P = 3\bar{h}_{CO2@25°C} + 4\bar{h}_{H2O@25°C} + 2\bar{h}_{O2@25°C} + 26.32\bar{h}_{N2@25°C} + N_w\,(\bar{h}_f^{\,o}{}_{H2O(liq)})$$

$$= 3(-393,520\,kJ/kmol) + 4(-241,820\,kJ/kmol) + 2(0) + 26.32(0) + 1.503(-285,830\,kJ/kmol)$$

$$= -2.577 \times 10^6\,kJ/kmol$$

Substituting into the energy balance equation,

$$\dot{N}_{fuel}H_R = \dot{Q}_{fuel} + \dot{N}_{fuel}H_P$$

$$\dot{N}_{fuel}(-103,847\,kJ/kmol) = 32,969\,kJ/h + \dot{N}_{fuel}(-2.577 \times 10^6\,kJ/kmol) \longrightarrow \dot{N}_{fuel} = 0.01333\,kmol/h$$

The molar and mass flow rates of the liquid water are

$$\dot{N}_w = N_w\dot{N}_{fuel} = (1.503\ kmol/kmol\,fuel)(0.01333\ kmol\,fuel/h) = 0.02003\ kmol/h$$

$$\dot{m}_w = \dot{N}_w M_w = (0.02003\ kmol/h)(18\ kg/kmol) = 0.3608\ kg/h$$

The volume flow rate of liquid water is

$$\dot{V}_w = (v_{f@25°C})\dot{m}_w = (0.001003\ m^3/kg)(0.3608\ kg/h) = 0.0003619\ m^3/h = \textbf{8.7 L/day}$$