15-89 Ethylene gas is burned steadily with 20 percent excess air. The temperature of products, the entropy generation, and the exergy destruction (or irreversibility) are to be determined.

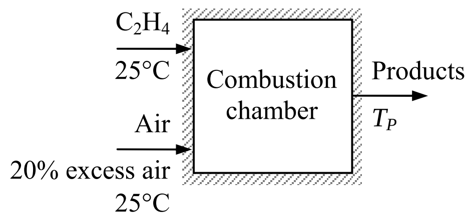
Assumptions **1** Combustion is complete. **2** Steady operating conditions exist. **3** Air and the combustion gases are ideal gases. **4** Changes in kinetic and potential energies are negligible.

Analysis (*a*) The fuel is burned completely with the excess air, and thus the products will contain only CO_2, H_2O, N_2, and some free O_2. Considering 1 kmol of C_2H_4, the combustion equation can be written as

$$\mathrm{C_2H_4(g)} + 1.2a_{\mathrm{th}}(\mathrm{O_2} + 3.76\mathrm{N_2}) \longrightarrow 2\mathrm{CO_2} + 2\mathrm{H_2O} + 0.2a_{\mathrm{th}}\mathrm{O_2} + (1.2)(3.76)a_{\mathrm{th}}\mathrm{N_2}$$

where a_{th} is the stoichiometric coefficient and is determined from the O_2 balance,

$$1.2a_{\mathrm{th}} = 2 + 1 + 0.2a_{\mathrm{th}} \quad \longrightarrow \quad a_{\mathrm{th}} = 3$$



Thus,

$$\mathrm{C_2H_4}(g) + 3.6(\mathrm{O_2} + 3.76\mathrm{N_2}) \longrightarrow 2\mathrm{CO_2} + 2\mathrm{H_2O} + 0.6\mathrm{O_2} + 13.54\mathrm{N_2}$$

Under steady-flow conditions, the exit temperature of the product gases can be determined from the steady-flow energy equation, which reduces to

$$\sum N_P\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_P = \sum N_R \bar{h}_{f,R}^\circ = \left(N\bar{h}_f^\circ\right)_{\mathrm{C_2H_4}}$$

since all the reactants are at the standard reference state, and for O_2 and N_2. From the tables,

Substance	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{298\ \mathrm{K}}$ kJ/kmol
C_2H_4 (*g*)	52,280	---
O_2	0	8682
N_2	0	8669
H_2O (*g*)	-241,820	9904
CO_2	-393,520	9364

Substituting,

$$(2)\left(-393{,}520 + \bar{h}_{\mathrm{CO_2}} - 9364\right) + (2)\left(-241{,}820 + \bar{h}_{\mathrm{H_2O}} - 9904\right)$$
$$+ (0.6)\left(0 + \bar{h}_{\mathrm{O_2}} - 8682\right) + (13.54)\left(0 + \bar{h}_{\mathrm{N_2}} - 8669\right) = (1)(52{,}280)$$

or,

$$2\bar{h}_{\mathrm{CO_2}} + 2\bar{h}_{\mathrm{H_2O}} + 0.6\bar{h}_{\mathrm{O_2}} + 13.54\bar{h}_{\mathrm{N_2}} = 1{,}484{,}083 \text{ kJ}$$

By trial and error,

$$T_P = \mathbf{2269.6\ K}$$

(*b*) The entropy generation during this adiabatic process is determined from

$$S_{\mathrm{gen}} = S_P - S_R = \sum N_P \bar{s}_P - \sum N_R \bar{s}_R$$

The C_2H_4 is at 25°C and 1 atm, and thus its absolute entropy is 219.83 kJ/kmol·K (Table A-26). The entropy values listed in the ideal gas tables are for 1 atm pressure. Both the air and the product gases are at a total pressure of 1 atm, but the entropies are to be calculated at the partial pressure of the components which is equal to $P_i = y_i\, P_{\mathrm{total}}$, where y_i is the mole fraction of component i. Also,

$$S_i = N_i \bar{s}_i(T, P_i) = N_i\left(\bar{s}_i^\circ(T, P_0) - R_u \ln(y_i P_m)\right)$$

The entropy calculations can be presented in tabular form as

	N_i	y_i	$\bar{s}_i^\circ(T,1\text{atm})$	$R_u \ln(y_i P_m)$	$N_i \bar{s}_i$
C_2H_4	1	1.00	219.83	---	219.83
O_2	3.6	0.21	205.14	-12.98	784.87
N_2	13.54	0.79	191.61	-1.96	2620.94
					S_R = 3625.64 kJ/K
CO_2	2	0.1103	316.881	-18.329	670.42
H_2O	2	0.1103	271.134	-18.329	578.93
O_2	0.6	0.0331	273.467	-28.336	181.08
N_2	13.54	0.7464	256.541	-2.432	3506.49
					S_P = 4936.92 kJ/K

Thus,

$$S_{\text{gen}} = S_P - S_R = 4936.92 - 3625.64 = \mathbf{1311.28\ kJ/kmol \cdot K}$$

and

(*c*) $$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (298\text{ K})(1311.28\text{ kJ/kmol}\cdot\text{K } C_2H_4) = \mathbf{390{,}760\ \ kJ}\ \ (\text{per kmol } C_2H_4)$$