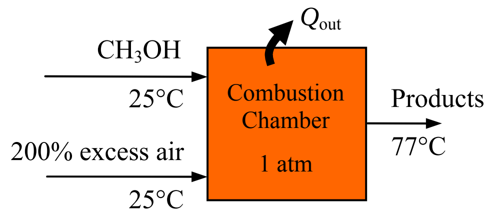
15-95 Methyl alcohol is burned steadily with 200 percent excess air in an automobile engine. The maximum amount of work that can be produced by this engine is to be determined.

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 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 CH_3OH the combustion equation can be written as

$$CH_3OH + 3a_{th}(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 2a_{th}O_2 + 3a_{th} \times 3.76N_2$$

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



$$0.5 + 3a_{th} = 1 + 1 + 2a_{th} \longrightarrow a_{th} = 1.5$$

Thus,

$$CH_3OH + 4.5(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 3O_2 + 16.92N_2$$

Under steady-flow conditions the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$ reduces to

$$-Q_{out} = \sum N_P\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_P - \sum N_R\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ\right)_R$$

Assuming the air and the combustion products to be ideal gases, we have $h = h(T)$. From the tables,

Substance	$\bar{\mathbf{h}}_f^\circ$ **kJ/kmol**	$\bar{\mathbf{h}}_{298K}$ **kJ/kmol**	$\bar{\mathbf{h}}_{350K}$ **kJ/kmol**
CH_3OH	-200,670	---	---
O_2	0	8682	10,213
N_2	0	8669	10,180
H_2O (*g*)	-241,820	9904	11,652
CO_2	-393,520	9364	11,351

Thus,

$$\begin{aligned}-Q_{out} &= (1)(-393{,}520 + 11{,}351 - 9364) + (2)(-241{,}820 + 11{,}652 - 9904) \\ &\quad + (3)(0 + 10{,}213 - 8682) + (16.92)(0 + 10{,}180 - 8669) - (1)(-200{,}670) \\ &= -663{,}550 \text{ kJ/kmol of fuel}\end{aligned}$$

The entropy generation during this process is determined from

$$S_{gen} = S_P - S_R + \frac{Q_{out}}{T_{surr}} = \sum N_P \bar{s}_P - \sum N_R \bar{s}_R + \frac{Q_{out}}{T_{surr}}$$

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 $P_i = y_i P_{total}$, where y_i is the mole fraction of component *i*. Then,

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

The entropy calculations can be presented in tabular form as

	N_i	y_i	$\bar{s}_i^\circ(T,1\text{atm})$	$R_u \ln(y_i P_m)$	$N_i \bar{s}_i$
CH_3OH	1	---	239.70	---	239.70
O_2	4.5	0.21	205.04	-12.98	981.09
N_2	16.92	0.79	191.61	-1.960	3275.20
					S_R = 4496 kJ/K
CO_2	1	0.0436	219.831	-26.05	245.88
H_2O (g)	2	0.0873	194.125	-20.27	428.79
O_2	3	0.1309	209.765	-16.91	680.03
N_2	16.92	0.7382	196.173	-2.52	3361.89
					S_P = 4717 kJ/K

Thus,

$$S_{\text{gen}} = S_P - S_R + \frac{Q_{\text{out}}}{T_{\text{surr}}} = 4717 - 4496 + \frac{663{,}550}{298} = 2448 \text{ kJ/K (per kmol fuel)}$$

The maximum work is equal to the exergy destruction

$$W_{\max} = X_{\text{dest}} = T_0 S_{\text{gen}} = (298)(2448 \text{ kJ/K}) = 729{,}400 \text{ kJ/K (per kmol fuel)}$$

Per unit mass basis,

$$W_{\max} = \frac{729{,}400 \text{ kJ/K} \cdot \text{kmol}}{32 \text{ kg/kmol}} = \mathbf{22{,}794 \text{ kJ/kg fuel}}$$