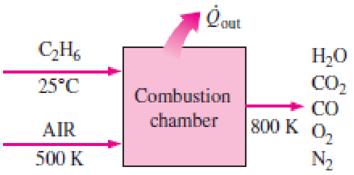
15–60 Ethane gas (C_2H_6) at 25°C is burned in a steady-flow combustion chamber at a rate of 5 kg/h with the stoichiometric amount of air, which is preheated to 500 K before entering the combustion chamber. An analysis of the combustion gases reveals that all the hydrogen in the fuel burns to H_2O but only 95 percent of the carbon burns to CO_2, the remaining 5 percent forming CO. If the products leave the combustion chamber at 800 K, determine the rate of heat transfer from the combustion chamber. *Answer:* 200,170 kJ/h

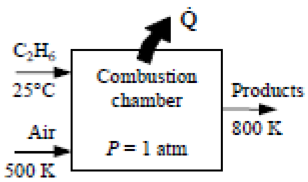


15-60 Ethane gas is burned with stoichiometric amount of air during a steady-flow combustion process. The rate of heat transfer from the combustion chamber is to be determined.

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

Properties The molar mass of C_2H_6 is 30 kg/kmol (Table A-1).

Analysis The theoretical combustion equation of C_2H_6 is



$$C_2H_6 + a_{th}(O_2 + 3.76N_2) \longrightarrow 2CO_2 + 3H_2O + 3.76a_{th}N_2$$

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

$$a_{th} = 2 + 1.5 = 3.5$$

Then the actual combustion equation can be written as

$$C_2H_6 + 3.5(O_2 + 3.76N_2) \longrightarrow 1.9CO_2 + 0.1CO + 3H_2O + 0.05O_2 + 13.16N_2$$

The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It 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	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{500\ K}$ kJ/kmol	$\bar{h}_{298\ K}$ kJ/kmol	$\bar{h}_{800\ K}$ kJ/kmol
C_2H_6 (*g*)	-84,680	---	---	---
O_2	0	14,770	8682	24,523
N_2	0	14,581	8669	23,714
H_2O (*g*)	-241,820	---	9904	27,896
CO	-110,530	---	8669	23,844
CO_2	-393,520	---	9364	32,179

Thus,

$$\begin{aligned}-Q_{out} &= (1.9)(-393{,}520 + 32{,}179 - 9364) + (0.1)(-110{,}530 + 23{,}844 - 8669)\\ &\quad + (3)(-241{,}820 + 27{,}896 - 9904) + (0.05)(0 + 24{,}523 - 8682) + (13.16)(0 + 23{,}714 - 8669)\\ &\quad - (1)(-84{,}680 + h_{298} - h_{298}) - (3.5)(0 + 14{,}770 - 8682) - (13.16)(0 + 14{,}581 - 8669)\\ &= -1{,}201{,}005 \text{ kJ / kmol } C_2H_6\end{aligned}$$

or $\quad Q_{out} = 1{,}201{,}005 \text{ kJ / kmol } C_2H_6$

Then the rate of heat transfer for a mass flow rate of 3 kg/h for the ethane becomes

$$\dot{Q}_{out} = \dot{N}Q_{out} = \left(\frac{\dot{m}}{M}\right)Q_{out} = \left(\frac{5 \text{ kg/h}}{30 \text{ kg/kmol}}\right)(1{,}201{,}005 \text{ kJ/kmol}) = \mathbf{200{,}170 \text{ kJ/h}}$$

15–56 Diesel fuel ($C_{12}H_{26}$) at 25°C is burned in a steady-flow combustion chamber with 20 percent excess air that also enters at 25°C. The products leave the combustion chamber at 500 K. Assuming combustion is complete, determine the required mass flow rate of the diesel fuel to supply heat at a rate of 2000 kJ/s. *Answer: 49.5 g/s*

15-56 Diesel fuel is burned with 20 percent excess air during a steady-flow combustion process. The required mass flow rate of the diesel fuel to supply heat at a specified rate is to be determined.

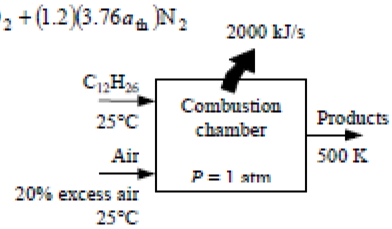
Assumptions **1** Steady operating conditions exist. **2** Air and combustion gases are ideal gases. **3** Kinetic and potential energies are negligible. **4** Combustion is complete.

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 of $C_{12}H_{26}$, the combustion equation can be written as

$$C_{12}H_{26} + 1.2a_{th}(O_2 + 3.76N_2) \longrightarrow 12CO_2 + 13H_2O + 0.2a_{th}O_2 + (1.2)(3.76a_{th})N_2$$

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

$$1.2a_{th} = 12 + 6.5 + 0.2a_{th} \longrightarrow a_{th} = 18.5$$



Substituting,

$$C_{12}H_{26} + 22.2(O_2 + 3.76N_2) \longrightarrow 12CO_2 + 13H_2O + 3.7O_2 + 83.47N_2$$

The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

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

since all of the reactants are at 25°C. Assuming the air and the combustion products to be ideal gases, we have $h = h(T)$. From the tables,

Substance	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{298\ K}$ kJ/kmol	$\bar{h}_{500\ K}$ kJ/kmol
$C_{12}H_{26}$	-291,010	---	---
O_2	0	8682	14,770
N_2	0	8669	14,581
H_2O (*g*)	-241,820	9904	16,828
CO_2	-393,520	9364	17,678

Thus,

$$\begin{aligned}-Q_{out} &= (12)(-393{,}520 + 17{,}678 - 9364) + (13)(-241{,}820 + 16{,}828 - 9904)\\ &\quad + (3.7)(0 + 14{,}770 - 8682) + (83.47)(0 + 14{,}581 - 8669) - (1)(-291{,}010) - 0 - 0\\ &= -6{,}869{,}110 \text{ kJ/kmol } C_{12}H_{26}\end{aligned}$$

or $\quad \dot{Q}_{out} = 6{,}869{,}110 \text{ kJ/kmol } C_{12}H_{26}$

Then the required mass flow rate of fuel for a heat transfer rate of 2000 kJ/s becomes

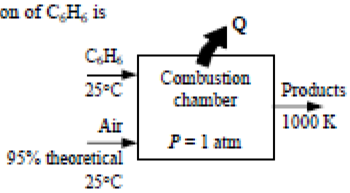
$$\dot{m} = \dot{N}M = \left(\frac{\dot{Q}_{out}}{Q_{out}}\right)M = \left(\frac{2000 \text{ kJ/s}}{6{,}869{,}110 \text{ kJ/kmol}}\right)(170 \text{ kg/kmol}) = 0.0495 \text{ kg/s} = \mathbf{49.5 \text{ g/s}}$$

15–55 Benzene gas (C_6H_6) at 25°C is burned during a steady-flow combustion process with 95 percent theoretical air that enters the combustion chamber at 25°C. All the hydrogen in the fuel burns to H_2O, but part of the carbon burns to CO. If the products leave at 1000 K, determine (*a*) the mole fraction of the CO in the products and (*b*) the heat transfer from the combustion chamber during this process. *Answers:* (*a*) 2.1 percent, (*b*) 2,112,800 kJ/kmol C_6H_6

15-55 Benzene gas is burned with 95 percent theoretical air during a steady-flow combustion process. The mole fraction of the CO in the products and the heat transfer from the combustion chamber are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Air and combustion gases are ideal gases. **3** Kinetic and potential energies are negligible.

Analysis (*a*) The fuel is burned with insufficient amount of air, and thus the products will contain some CO as well as CO_2, H_2O, and N_2. The theoretical combustion equation of C_6H_6 is



$$C_6H_6 + a_{th}(O_2 + 3.76N_2) \longrightarrow 6CO_2 + 3H_2O + 3.76a_{th}N_2$$

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

$$a_{th} = 6 + 1.5 = 7.5$$

Then the actual combustion equation can be written as

$$C_6H_6 + 0.95 \times 7.5(O_2 + 3.76N_2) \longrightarrow xCO_2 + (6-x)CO + 3H_2O + 26.79N_2$$

O_2 balance: $\quad 0.95 \times 7.5 = x + (6-x)/2 + 1.5 \longrightarrow x = 5.25$

Thus, $\quad C_6H_6 + 7.125(O_2 + 3.76N_2) \longrightarrow 5.25CO_2 + 0.75CO + 3H_2O + 26.79N_2$

The mole fraction of CO in the products is

$$y_{CO} = \frac{N_{CO}}{N_{total}} = \frac{0.75}{5.25 + 0.75 + 3 + 26.79} = 0.021 \quad \text{or} \quad \mathbf{2.1\%}$$

(*b*) The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

$$-Q_{out} = \sum N_P\left(\overline{h}_f^\circ + \overline{h} - \overline{h}^\circ\right)_P - \sum N_R\left(\overline{h}_f^\circ + \overline{h} - \overline{h}^\circ\right)_R = \sum N_P\left(\overline{h}_f^\circ + \overline{h} - \overline{h}^\circ\right)_P - \sum N_R \overline{h}_{f,R}^\circ$$

since all of the reactants are at 25°C. Assuming the air and the combustion products to be ideal gases, we have $h = h(T)$. From the tables,

Substance	$\overline{h}_f^\circ$ kJ/kmol	$\overline{h}_{298\ K}$ kJ/kmol	$\overline{h}_{1000\ K}$ kJ/kmol
C_6H_6 (*g*)	82,930	---	---
O_2	0	8682	31,389
N_2	0	8669	30,129
H_2O (*g*)	-241,820	9904	35,882
CO	-110,530	8669	30,355
CO_2	-393,520	9364	42,769

Thus,

$$\begin{aligned} -Q_{out} &= (5.25)(-393{,}520 + 42{,}769 - 9364) + (0.75)(-110{,}530 + 30{,}355 - 8669) \\ &\quad + (3)(-241{,}820 + 35{,}882 - 9904) + (26.79)(0 + 30{,}129 - 8669) - (1)(82{,}930) - 0 - 0 \\ &= -2{,}112{,}779 \text{ kJ / kmol } C_6H_6 \end{aligned}$$

or $\quad \dot{Q}_{out} = \mathbf{2{,}112{,}800\ kJ/kmol\ C_6H_6}$

15–53 Acetylene gas (C_2H_2) is burned completely with 20 percent excess air during a steady-flow combustion process. The fuel and air enter the combustion chamber at 25°C, and the products leave at 1500 K. Determine (*a*) the air–fuel ratio and (*b*) the heat transfer for this process.

15-53 Acetylene gas is burned with 20 percent excess air during a steady-flow combustion process. The AF ratio and the heat transfer are to be determined.

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

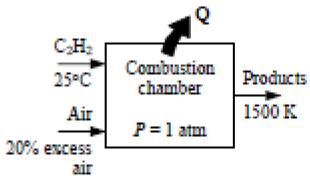
Properties The molar masses of C_2H_2 and air are 26 kg/kmol and 29 kg/kmol, respectively (Table A-1).

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 of C_2H_2, the combustion equation can be written as

$$C_2H_2 + 1.2a_{th}(O_2 + 3.76N_2) \longrightarrow 2CO_2 + H_2O + 0.2a_{th}O_2 + (1.2)(3.76a_{th})N_2$$

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

$$1.2a_{th} = 2 + 0.5 + 0.2a_{th} \quad \longrightarrow \quad a_{th} = 2.5$$



Thus,

$$C_2H_2 + 3(O_2 + 3.76N_2) \longrightarrow 2CO_2 + H_2O + 0.5O_2 + 11.28N_2$$

(*a*) $$\text{AF} = \frac{m_{air}}{m_{fuel}} = \frac{(3\times 4.76\text{ kmol})(29\text{ kg/kmol})}{(2\text{ kmol})(12\text{ kg/kmol}) + (1\text{ kmol})(2\text{ kg/kmol})} = \mathbf{15.9\ kg\ air/kg\ fuel}$$

(*b*) The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

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

since all of the reactants are at 25°C. Assuming the air and the combustion products to be ideal gases, we have $h = h(T)$. From the tables,

Substance	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{298\text{ K}}$ kJ/kmol	$\bar{h}_{1500\text{ K}}$ kJ/kmol
C_2H_2	226,730	---	---
O_2	0	8682	49,292
N_2	0	8669	47,073
H_2O (*g*)	-241,820	9904	57,999
CO_2	-393,520	9364	71,078

Thus,

$$\begin{aligned} -Q_{out} &= (2)(-393{,}520 + 71{,}078 - 9364) + (1)(-241{,}820 + 57{,}999 - 9904) + (0.5)(0 + 49{,}292 - 8682) \\ &\quad + (11.28)(0 + 47{,}073 - 8669) - (1)(226{,}730) - 0 - 0 \\ &= -630{,}565\text{ kJ/kmol } C_2H_2 \end{aligned}$$

or

$$Q_{out} = \mathbf{630{,}565\ kJ/kmol\ C_2H_2}$$

15-51 Liquid propane is burned with 150 percent excess air during a steady-flow combustion process. The mass flow rate of air and the rate of heat transfer from the combustion chamber are to be determined.

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

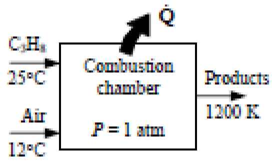
Properties The molar masses of propane and air are 44 kg/kmol and 29 kg/kmol, respectively (Table A-1).

Analysis The fuel is burned completely with 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_3H_8, the combustion equation can be written as

$$C_3H_8(\ell) + 2.5a_{th}(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 1.5a_{th}O_2 + (2.5)(3.76a_{th})N_2$$

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

$$2.5a_{th} = 3 + 2 + 1.5a_{th} \longrightarrow a_{th} = 5$$



Thus,

$$C_3H_8(\ell) + 12.5(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 7.5O_2 + 47N_2$$

(*a*) The air-fuel ratio for this combustion process is

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(12.5 \times 4.76 \text{ kmol})(29 \text{ kg/kmol})}{(3 \text{ kmol})(12 \text{ kg/kmol}) + (4 \text{ kmol})(2 \text{ kg/kmol})} = 39.22 \text{ kg air/kg fuel}$$

Thus, $\dot{m}_{air} = (AF)(\dot{m}_{fuel}) = (39.22 \text{ kg air/kg fuel})(1.2 \text{ kg fuel/min}) = \mathbf{47.1\ kg\ air/min}$

(*b*) The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It 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	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{285\ K}$ kJ/kmol	$\bar{h}_{298\ K}$ kJ/kmol	$\bar{h}_{1200\ K}$ kJ/kmol
C_3H_8 (ℓ)	-118,910	---	---	---
O_2	0	8296.5	8682	38,447
N_2	0	8286.5	8669	36,777
H_2O (*g*)	-241,820	---	9904	44,380
CO_2	-393,520	---	9364	53,848

The $\bar{h}_f^\circ$ of liquid propane is obtained by adding $\bar{h}_{fg}$ of propane at 25°C to $\bar{h}_f^\circ$ of gas propane. Substituting,

$$\begin{aligned}-Q_{out} &= (3)(-393{,}520 + 53{,}848 - 9364) + (4)(-241{,}820 + 44{,}380 - 9904) + (7.5)(0 + 38{,}447 - 8682) \\ &\quad + (47)(0 + 36{,}777 - 8669) - (1)(-118{,}910 + h_{298} - h_{298}) - (12.5)(0 + 8296.5 - 8682) \\ &\quad - (47)(0 + 8286.5 - 8669) \\ &= -190{,}464 \text{ kJ/kmol } C_3H_8\end{aligned}$$

or $\quad Q_{out} = 190{,}464 \text{ kJ/kmol } C_3H_8$

Then the rate of heat transfer for a mass flow rate of 1.2 kg/min for the propane becomes

$$\dot{Q}_{out} = \dot{N}Q_{out} = \left(\frac{\dot{m}}{N}\right)Q_{out} = \left(\frac{1.2 \text{ kg/min}}{44 \text{ kg/kmol}}\right)(190{,}464 \text{ kJ/kmol}) = \mathbf{5194\ kJ/min}$$

15–51 Liquid propane (C_3H_8) enters a combustion chamber at 25°C at a rate of 1.2 kg/min where it is mixed and burned with 150 percent excess air that enters the combustion chamber at 12°C. If the combustion is complete and the exit

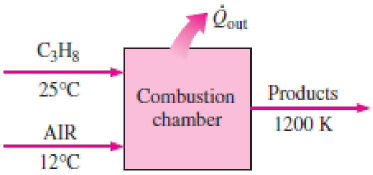


FIGURE P15–51

temperature of the combustion gases is 1200 K, determine (*a*) the mass flow rate of air and (*b*) the rate of heat transfer from the combustion chamber. *Answers:* (*a*) 47.1 kg/min, (*b*) 5194 kJ/min

15-51 Liquid propane is burned with 150 percent excess air during a steady-flow combustion process. The mass flow rate of air and the rate of heat transfer from the combustion chamber are to be determined.

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

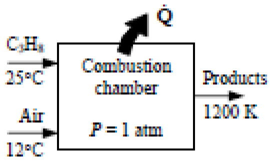
Properties The molar masses of propane and air are 44 kg/kmol and 29 kg/kmol, respectively (Table A-1).

Analysis The fuel is burned completely with 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_3H_8, the combustion equation can be written as

$$C_3H_8(\ell) + 2.5a_{th}(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 1.5a_{th}O_2 + (2.5)(3.76a_{th})N_2$$

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

$$2.5a_{th} = 3 + 2 + 1.5a_{th} \longrightarrow a_{th} = 5$$



Thus,

$$C_3H_8(\ell) + 12.5(O_2 + 3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 7.5O_2 + 47N_2$$

(*a*) The air-fuel ratio for this combustion process is

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(12.5 \times 4.76\text{ kmol})(29\text{ kg/kmol})}{(3\text{ kmol})(12\text{ kg/kmol}) + (4\text{ kmol})(2\text{ kg/kmol})} = 39.22\text{ kg air/kg fuel}$$

Thus, $\dot{m}_{air} = (AF)(\dot{m}_{fuel}) = (39.22\text{ kg air/kg fuel})(1.2\text{ kg fuel/min}) = \mathbf{47.1\ kg\ air/min}$

(*b*) The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It 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	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{285\ K}$ kJ/kmol	$\bar{h}_{298\ K}$ kJ/kmol	$\bar{h}_{1200\ K}$ kJ/kmol
C_3H_8 (ℓ)	-118,910	---	---	---
O_2	0	8296.5	8682	38,447
N_2	0	8286.5	8669	36,777
H_2O (g)	-241,820	---	9904	44,380
CO_2	-393,520	---	9364	53,848

The $\bar{h}_f^\circ$ of liquid propane is obtained by adding $\bar{h}_{fg}$ of propane at 25°C to $\bar{h}_f^\circ$ of gas propane. Substituting,

$$\begin{aligned}-Q_{out} &= (3)(-393{,}520 + 53{,}848 - 9364) + (4)(-241{,}820 + 44{,}380 - 9904) + (7.5)(0 + 38{,}447 - 8682) \\ &\quad + (47)(0 + 36{,}777 - 8669) - (1)(-118{,}910 + h_{298} - h_{298}) - (12.5)(0 + 8296.5 - 8682) \\ &\quad - (47)(0 + 8286.5 - 8669) \\ &= -190{,}464\text{ kJ/kmol }C_3H_8\end{aligned}$$

or $\quad Q_{out} = 190{,}464\text{ kJ/kmol }C_3H_8$

Then the rate of heat transfer for a mass flow rate of 1.2 kg/min for the propane becomes

$$\dot{Q}_{out} = \dot{N}Q_{out} = \left(\frac{\dot{m}}{N}\right)Q_{out} = \left(\frac{1.2\text{ kg/min}}{44\text{ kg/kmol}}\right)(190{,}464\text{ kJ/kmol}) = \mathbf{5194\ kJ/min}$$

15–50 Hydrogen (H_2) is burned completely with the stoichiometric amount of air during a steady-flow combustion process. If both the reactants and the products are maintained at 25°C and 1 atm and the water in the products exists in the liquid form, determine the heat transfer from the combustion chamber during this process. What would your answer be if combustion were achieved with 50 percent excess air?

15-50 Hydrogen is burned completely during a steady-flow combustion process. The heat transfer from the combustion chamber is to be determined for two cases.

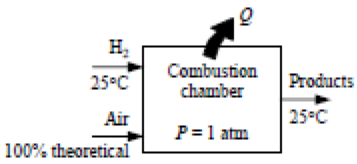
Assumptions **1** Steady operating conditions exist. **2** Air and combustion gases are ideal gases. **3** Kinetic and potential energies are negligible. **4** Combustion is complete.

Analysis The H_2 is burned completely with the stoichiometric amount of air, and thus the products will contain only H_2O and N_2, but no free O_2. Considering 1 kmol of H_2, the theoretical combustion equation can be written as

$$H_2 + a_{th}(O_2 + 3.76N_2) \longrightarrow H_2O + 3.76a_{th}N_2$$

where a_{th} is determined from the O_2 balance to be $a_{th} = 0.5$. Substituting,

$$H_2 + 0.5(O_2 + 3.76N_2) \longrightarrow H_2O + 1.88N_2$$



The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

$$-Q_{out} = \sum N_P\left(\overline{h}_f^\circ + \overline{h} - \overline{h}^\circ\right)_P - \sum N_R\left(\overline{h}_f^\circ + \overline{h} - \overline{h}^\circ\right)_R = \sum N_P\overline{h}_{f,P}^\circ - \sum N_R\overline{h}_{f,R}^\circ$$

since both the reactants and the products are at 25°C and both the air and the combustion gases can be treated as ideal gases. From the tables,

Substance	$\overline{h}_f^\circ$ kJ/kmol
H_2	0
O_2	0
N_2	0
H_2O (ℓ)	-285,830

Substituting,

$$-Q_{out} = (1)(-285{,}830) + 0 - 0 - 0 - 0 = -285{,}830 \text{ kJ / kmol } H_2$$

or

$$Q_{out} = \mathbf{285{,}830 \text{ kJ / kmol } H_2}$$

If combustion is achieved with 50% excess air, the answer would still be the same since it would enter and leave at 25°C, and absorb no energy.

15–49 Methane (CH_4) is burned completely with the stoichiometric amount of air during a steady-flow combustion process. If both the reactants and the products are maintained at 25°C and 1 atm and the water in the products exists in the liquid form, determine the heat transfer from the combustion chamber during this process. What would your answer be if combustion were achieved with 100 percent excess air? *Answer:* 890,330 kJ/kmol

15-49 Methane is burned completely during a steady-flow combustion process. The heat transfer from the combustion chamber is to be determined for two cases.

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

Analysis The fuel is burned completely with the stoichiometric amount of air, and thus the products will contain only H_2O, CO_2 and N_2, but no free O_2. Considering 1 kmol of fuel, the theoretical combustion equation can be written as

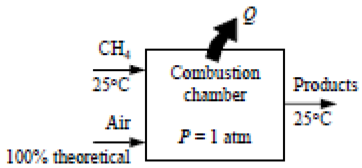
$$CH_4 + a_{th}(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 3.76a_{th}N_2$$

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

$$a_{th} = 1 + 1 = 2$$

Substituting,

$$CH_4 + 2(O_2 + 3.76N_2) \longrightarrow CO_2 + 2H_2O + 5.64N_2$$



The heat transfer for this combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

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

since both the reactants and the products are at 25°C and both the air and the combustion gases can be treated as ideal gases. From the tables,

Substance	$\bar{h}_f^\circ$ **kJ/kmol**
CH_4	-74,850
O_2	0
N_2	0
H_2O (ℓ)	-285,830
CO_2	-393,520

Thus,

$$-Q_{out} = (1)(-393{,}520) + (2)(-285{,}830) + 0 - (1)(-74{,}850) - 0 - 0 = -890{,}330 \text{ kJ / kmol } CH_4$$

or

$$Q_{out} = \mathbf{890{,}330 \text{ kJ / kmol } CH_4}$$

If combustion is achieved with 100% excess air, the answer would still be the same since it would enter and leave at 25°C, and absorb no energy.