$$M = \sum_{i=1}^{j} y_i M_i$$

$$M \approx 0.7808(28.02) + 0.2095(32.00) + 0.0093(39.94) + 0.0003(44.01)$$
$$= 28.97 \text{ kg/kmol}$$

دالتون مدل : هر جز گازی در یک مخلوط مانند یک گاز کامل تنها که در همان دماو حجم قرار گرفته است عمل می کند.

$$\frac{p_i}{p} = \frac{n_i \overline{R}T/V}{n\overline{R}T/V} = \frac{n_i}{n} = y_i \qquad\qquad \frac{V_i}{V} = \frac{n_i\overline{R}T/p}{n\overline{R}T/p} = \frac{n_i}{n} = y_i$$

CLOSING COMMENT. The Dalton and Amagat models are special cases, respectively, of the additive pressure and additive volume rules introduced in Sec. 11.8, which do not require the assumption of the ideal gas model. The concept of an ideal gas mixture is a special case of the *ideal solution* concept introduced in Sec. 11.9.

$$n\overline{u} = n_1\overline{u}_1 + n_2\overline{u}_2 + \cdots + n_j\overline{u}_j = \sum_{i=1}^{J} n_i\overline{u}_i \qquad \overline{u} = \sum_{i=1}^{j} y_i\overline{u}_i \qquad \overline{u} = Mu,$$
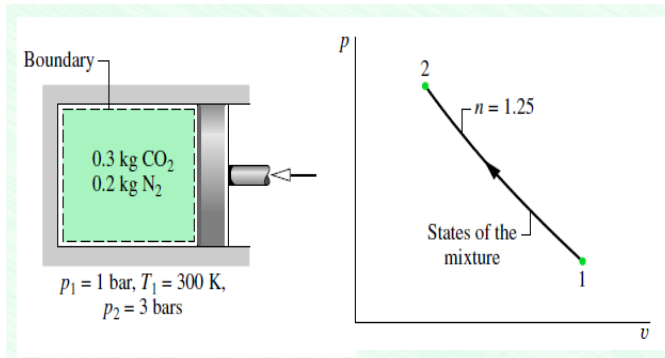
$$s_i = s_{0i} + C_{p0i} \ln\left(\frac{T}{T_0}\right) - R_i \ln\left(\frac{y_i P}{P_0}\right)$$

$$(s_2 - s_1)_i = s_{0i} - s_{0i} + C_{p0i}\left[\ln\frac{T_2}{T_0} - \ln\frac{T_1}{T_0}\right] - R_i\left[\ln\frac{y_i P_2}{P_0} - \ln\frac{y_i P_1}{P_0}\right]$$

$$= 0 + C_{p0i}\ln\left[\frac{T_2}{T_0} \times \frac{T_0}{T_1}\right] - R_i \ln\left[\frac{y_i P_2}{P_0} \times \frac{P_0}{y_i P_1}\right]$$

$$= C_{p0i}\ln\frac{T_2}{T_1} - R_i\ln\frac{P_2}{P_1}$$

$$s_i = s_{T_i}^0 - R_i \ln\left(\frac{y_i P}{P_0}\right)$$

$$s_2 - s_1 = c_A(s_2 - s_1)_A + c_B(s_2 - s_1)_B$$

$$= c_A C_{p0A}\ln\frac{T_2}{T_1} - c_A R_A \ln\frac{P_2}{P_1} + c_B C_{p0B}\ln\frac{T_2}{T_1} - c_B R_B \ln\frac{P_2}{P_1}$$

$$= C_{p0\text{ mix}}\ln\frac{T_2}{T_1} - R_{\text{mix}}\ln\frac{P_2}{P_1}$$

A mixture of 0.3 kg of carbon dioxide and 0.2 kg of nitrogen is compressed from $p_1 = 1$ bar, $T_1 = 300$ K to $p_2 = 3$ bars in a polytropic process for which $n = 1.25$. Determine (a) the final temperature, in K, (b) the work, in kJ, (c) the heat transfer, in kJ, (d) the change in entropy of the mixture, in kJ/K.

Boundary

0.3 kg CO_2
0.2 kg N_2

$p_1 = 1$ bar, $T_1 = 300$ K,
$p_2 = 3$ bars

P

2

$n = 1.25$

States of the
mixture

1

v

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{(n-1)/n}$$

$$n_{CO_2} = \frac{0.3}{44} = 0.0068 \text{ kmol}, \qquad n_{N_2} = \frac{0.2}{28} = 0.0071 \text{ kmol}$$

$$T_2 = 300\left(\frac{3}{1}\right)^{0.2} = 374 \text{ K}$$

iven by

$$W = \int_1^2 p\,dV$$

$$W = \frac{(0.5 \text{ kg})\left(\dfrac{8.314 \text{ kJ}}{35.97 \text{ kg} \cdot {}^\circ\text{K}}\right)(374 \text{ K} - 300 \text{ K})}{1 - 1.25}$$

$$= -34.21 \text{ kJ}$$

e integration

the closed system energy balance can be placed in the form

$$W = \frac{p_2 V_2 - p_1 V_1}{1 - n}$$

$$Q = \Delta U + W$$

es to

$$W = \frac{m(\overline{R}/M)(T_2 - T_1)}{1 - n}$$

$$\Delta U = n_{CO_2}[\overline{u}_{CO_2}(T_2) - \overline{u}_{CO_2}(T_1)] + n_{N_2}[\overline{u}_{N_2}(T_2) - \overline{u}_{N_2}(T_1)]$$

$$\Delta U = (0.0068)(9198 - 6939) + (0.0071)(7770 - 6229)$$
$$= 26.3 \, \text{kJ}$$

into the expression for Q

$$Q = +26.3 - 34.21 = -7.91 \, \text{kJ}$$

$$\Delta S = n_{CO_2} \Delta \bar{s}_{CO_2} + n_{N_2} \Delta \bar{s}_{N_2}$$

using Eq. 12.36 and values of $\bar{s}^\circ$ for N_2 and CO_2 from Table

$$\Delta S = 0.0068 \left(222.475 - 213.915 - 8.314 \frac{3}{1} \right)$$
$$+ 0.0071 \left(198.105 - 191.682 - 8.314 \frac{3}{1} \right)$$
$$= -.0231 \, \text{kJ/K}$$

Two rigid, insulated tanks are interconnected by a valve. Initially 0.79 kmol of nitrogen at 2 bars and 250 K fills one tank. The other tank contains 0.21 kmol of oxygen at 1 bar and 300 K. The valve is opened and the gases are allowed to mix until a final equilibrium state is attained. During this process, there are no heat or work interactions between the tank contents and the surroundings. Determine (a) the final temperature of the mixture, in °K, (b) the final pressure of the mixture, in atm, (c) the amount of entropy produced in the mixing process, in kJ/K.

$$U_2 = n_{N_2} \bar{u}_{N_2}(T_2) + n_{O_2} \bar{u}_{O_2}(T_2) \qquad U_1 = n_{N_2} \bar{u}_{N_2}(T_{N_2}) + n_{O_2} \bar{u}_{O_2}(T_{O_2})$$

$$n_{N_2}[\bar{u}_{N_2}(T_2) - \bar{u}_{N_2}(T_{N_2})] + n_{O_2}[\bar{u}_{O_2}(T_2) - \bar{u}_{O_2}(T_{O_2})] = 0$$

$$T_2 = \frac{n_{N_2} \bar{c}_{v,N_2} T_{N_2} + n_{O_2} \bar{c}_{v,O_2} T_{O_2}}{n_{N_2} \bar{c}_{v,N_2} + n_{O_2} \bar{c}_{v,O_2}} \qquad n_{N_2} \bar{c}_{v,N_2}(T_2 - T_{N_2}) + n_{O_2} \bar{c}_{v,O_2}(T_2 - T_{O_2}) = 0$$

$$p_2 = \frac{(n_{N_2} + n_{O_2})T_2}{\left(\dfrac{n_{N_2}T_{N_2}}{p_{N_2}} + \dfrac{n_{O_2}T_{O_2}}{p_{O_2}}\right)}$$

$$S_1 = n_{N_2}\bar{s}_{N_2}(T_{N_2}, p_{N_2}) + n_{O_2}\bar{s}_{O_2}(T_{O_2}, p_{O_2})$$

$$S_2 = n_{N_2}\bar{s}_{N_2}(T_2, y_{N_2}p_2) + n_{O_2}\bar{s}_{O_2}(T_2, y_{O_2}p_2)$$

$$\sigma = n_{N_2}[\bar{s}_{N_2}(T_2, y_{N_2}p_2) - \bar{s}_{N_2}(T_{N_2}, p_{N_2})]$$
$$+ n_{O_2}[\bar{s}_{O_2}(T_2, y_{O_2}p_2) - \bar{s}_{O_2}(T_{O_2}, p_{O_2})]$$

$$\sigma = n_{N_2}\left(\bar{c}_{p,N_2}\ln\frac{T_2}{T_{N_2}} - \bar{R}\ln\frac{y_{N_2}p_2}{p_{N_2}}\right)$$
$$+ n_{O_2}\left(\bar{c}_{p,O_2}\ln\frac{T_2}{T_{O_2}} - \bar{R}\ln\frac{y_{O_2}p_2}{p_{O_2}}\right)$$

At steady state, 100 m³/min of dry air at 32°C and 1 bar is mixed adiabatically with a stream of oxygen (O_2) at 127°C and 1 bar to form a mixed stream at 47°C and 1 bar. Kinetic and potential energy effects can be ignored. Determine (a) the mass flow rates of the dry air and oxygen, in kg/min, (b) the mole fractions of the dry air and oxygen in the exiting mixture, and (c) the time rate of entropy production, in kJ/K · min.
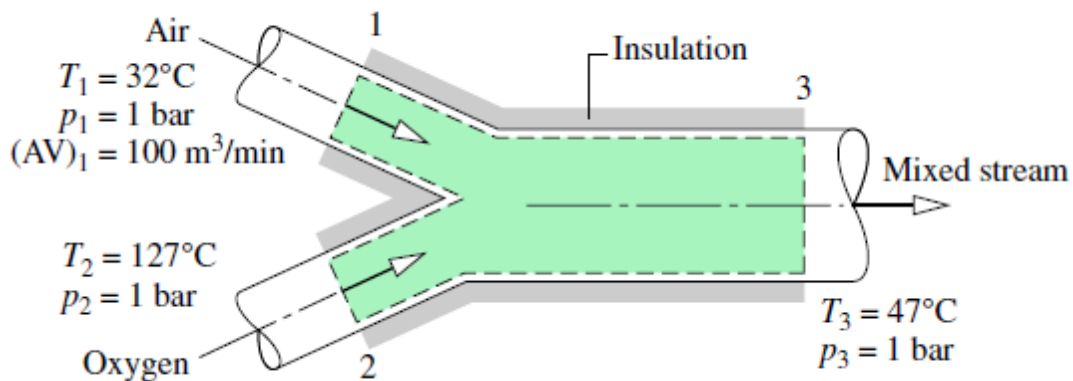
$$\dot{m}_{a1} = \frac{(AV)_1}{v_{a1}}$$

ne of the air at 1. Using the ideal gas equation of state

$$v_{a1} = \frac{(\bar{R}/M_a)T_1}{p_1} = \frac{\left(\dfrac{8314 \ \text{N} \cdot \text{m}}{28.97 \ \text{kg} \cdot \text{K}}\right)(305 \ \text{K})}{10^5 \ \text{N/m}^2} = 0.875 \ \frac{\text{m}^3}{\text{kg}}$$

$\dot{m}_{a1} = \dot{m}_{a3}$ (dry air)

$\dot{m}_{o2} = \dot{m}_{o3}$ (oxygen) $\dot{m}_{a1} = \dfrac{100 \ \text{m}^3/\text{min}}{0.875 \ \text{m}^3/\text{kg}} = 114.29 \ \dfrac{\text{kg}}{\text{min}}$

$$0 = \dot{m}_a h_a(T_1) + \dot{m}_o h_o(T_2) - [\dot{m}_a h_a(T_3) + \dot{m}_o h_o(T_3)]$$

$$\dot{m}_o = \dot{m}_a \left[\frac{h_a(T_3) - h_a(T_1)}{h_o(T_2) - h_o(T_3)} \right]$$

$$\dot{m}_o = \frac{(114.29 \ \text{kg/min})(320.29 \ \text{kJ/kg} - 305.22 \ \text{kJ/kg})}{\left(\dfrac{1}{32 \ \text{kg/kmol}}\right)(11{,}711 \ \text{kJ/kmol} - 9{,}325 \ \text{kJ/kmol})}$$

$$= 23.1 \ \frac{\text{kg}}{\text{min}}$$

$$\dot{n}_a = \frac{\dot{m}_a}{M_a} = \frac{114.29 \ \text{kg/min}}{28.97 \ \text{kg/kmol}} = 3.95 \ \text{kmol/min}$$

$$\dot{n}_o = \frac{\dot{m}_o}{M_o} = \frac{23.1 \ \text{kg/min}}{32 \ \text{kg/kmol}} = 0.72 \ \text{kmol/min}$$

$$\dot{n} = \dot{n}_a + \dot{n}_o = 3.95 + 0.72 = 4.67 \ \text{kmol/min}$$

$$y_a = \frac{\dot{n}_a}{\dot{n}} = \frac{3.95}{4.67} = 0.846 \quad \text{and} \quad y_o = \frac{\dot{n}_o}{\dot{n}} = \frac{0.72}{4.67} = 0.154$$

$$\dot{\sigma} = \dot{m}_a[s_a(T_3, y_a p_3) - s_a(T_1, p_1)] + \dot{m}_o[s_o(T_3, y_o p_3) - s_o(T_2, p_2)]$$

13-67 The volume fractions of components of a gas mixture passing through the turbine of a simple ideal Brayton cycle are given. The thermal efficiency of this cycle is to be determined.

Assumptions All gases will be modeled as ideal gases with constant specific heats.

Properties The molar masses of N_2, O_2, H_2O, and CO_2 are 28.0, 32.0, 18.0, and 44.0 kg/kmol, respectively (Table A-1). The constant-pressure specific heats of these gases at room temperature are 1.039, 0.918, 1.8723, and 0.846 kJ/kg·K, respectively. The air properties at room temperature are $c_p = 1.005$ kJ/kg·K, $c_v = 0.718$ kJ/kg·K, $k = 1.4$ (Table A-2a).

Analysis We consider 100 kmol of this mixture. Noting that volume fractions are equal to the mole fractions, mass of each component are

$$m_{N2} = N_{N2} M_{N2} = (30\,\text{kmol})(28\,\text{kg/kmol}) = 840\,\text{kg}$$

$$m_{O2} = N_{O2} M_{O2} = (10\,\text{kmol})(32\,\text{kg/kmol}) = 320\,\text{kg}$$

$$m_{H2O} = N_{H2O} M_{H2O} = (20\,\text{kmol})(18\,\text{kg/kmol}) = 360\,\text{kg}$$

$$m_{CO2} = N_{CO2} M_{CO2} = (40\,\text{kmol})(44\,\text{kg/kmol}) = 1760\,\text{kg}$$

30% N_2, 10% O_2
20% H_2O, 40% CO_2
(by volume)

100 kPa

The total mass is

$$\begin{aligned} m_m &= m_{N2} + m_{O2} + m_{H2O} + m_{CO2} \\ &= 840 + 320 + 360 + 1760 \\ &= 3280\,\text{kg} \end{aligned}$$

Then the mass fractions are

$$\text{mf}_{N2} = \frac{m_{N2}}{m_m} = \frac{840\,\text{kg}}{3280\,\text{kg}} = 0.2561$$

$$\text{mf}_{O2} = \frac{m_{O2}}{m_m} = \frac{320\,\text{kg}}{3280\,\text{kg}} = 0.09756$$

$$\text{mf}_{H2O} = \frac{m_{H2O}}{m_m} = \frac{360\,\text{kg}}{3280\,\text{kg}} = 0.1098$$

$$\text{mf}_{CO2} = \frac{m_{CO2}}{m_m} = \frac{1760\,\text{kg}}{3280\,\text{kg}} = 0.5366$$

T-s diagram: points 1 (293 K), 2, 3 (1273 K), 4 with q_{in} between 2 and 3, q_{out} between 4 and 1.

The constant-pressure specific heat of the mixture is determined from

$$\begin{aligned} c_p &= \text{mf}_{N2} c_{p,N2} + \text{mf}_{O2} c_{p,O2} + \text{mf}_{H2O} c_{p,H2O} + \text{mf}_{CO2} c_{p,CO2} \\ &= 0.2561 \times 1.039 + 0.09756 \times 0.918 + 0.1098 \times 1.8723 + 0.5366 \times 0.846 \\ &= 1.015\,\text{kJ/kg} \cdot \text{K} \end{aligned}$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{3280\,\text{kg}}{100\,\text{kmol}} = 32.80\,\text{kg/kmol}$$

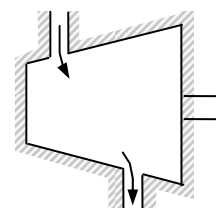The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{8.314\,\text{kJ/kmol} \cdot \text{K}}{32.80\,\text{kg/kmol}} = 0.2535\,\text{kJ/kg} \cdot \text{K}$$

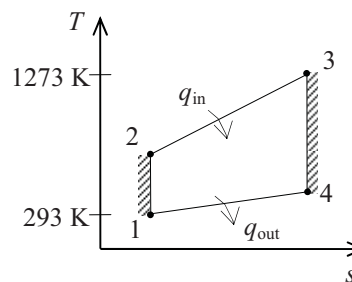Then the constant-volume specific heat is

$$c_v = c_p - R = 1.015 - 0.2535 = 0.762\,\text{kJ/kg} \cdot \text{K}$$

The specific heat ratio is

$$k = \frac{c_p}{c_v} = \frac{1.015}{0.762} = 1.332$$

The average of the air properties at room temperature and combustion gas properties are

$$c_{p,\text{avg}} = 0.5(1.015 + 1.005) = 1.010 \text{ kJ/kg} \cdot \text{K}$$
$$c_{v,\text{avg}} = 0.5(0.762 + 0.718) = 0.740 \text{ kJ/kg} \cdot \text{K}$$
$$k_{\text{avg}} = 0.5(1.332 + 1.4) = 1.366$$

These average properties will be used for heat addition and rejection processes. For compression, the air properties at room temperature and during expansion, the mixture properties will be used. During the compression process,

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{(k-1)/k} = (293 \text{ K})(8)^{0.4/1.4} = 531 \text{ K}$$

During the heat addition process,

$$q_{\text{in}} = c_{p,\text{avg}} (T_3 - T_2) = (1.010 \text{ kJ/kg} \cdot \text{K})(1273 - 531) \text{ K} = 749.4 \text{ kJ/kg}$$

During the expansion process,

$$T_4 = T_3 \left(\frac{P_4}{P_3} \right)^{(k-1)/k} = (1273 \text{ K}) \left(\frac{1}{8} \right)^{0.332/1.332} = 758 \text{ K}$$

During the heat rejection process,

$$q_{\text{out}} = c_{p,\text{avg}} (T_4 - T_1) = (1.010 \text{ kJ/kg} \cdot \text{K})(758 - 293) \text{ K} = 469.7 \text{ kJ/kg}$$

The thermal efficiency of the cycle is then

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{469.7 \text{ kJ/kg}}{749.4 \text{ kJ/kg}} = \mathbf{0.373}$$

The thermal efficiency of the standard air cycle is 43%

13-65E The volume fractions of components of a gas mixture during the expansion process of the ideal Otto cycle are given. The thermal efficiency of this cycle is to be determined.

Assumptions All gases will be modeled as ideal gases with constant specific heats.

Properties The molar masses of N_2, O_2, H_2O, and CO_2 are 28.0, 32.0, 18.0, and 44.0 lbm/lbmol, respectively (Table A-1E). The constant-pressure specific heats of these gases at room temperature are 0.248, 0.219, 0.445, and 0.203 Btu/lbm·R, respectively. The air properties at room temperature are c_p = 0.240 Btu/lbm·R, c_v = 0.171 Btu/lbm·R, k = 1.4 (Table A-2Ea).

Analysis We consider 100 lbmol of this mixture. Noting that volume fractions are equal to the mole fractions, mass of each component are

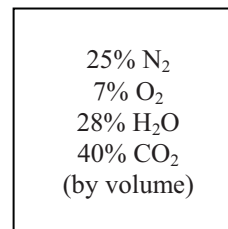$$m_{N2} = N_{N2} M_{N2} = (25\ \text{lbmol})(28\ \text{lbm/lbmol}) = 700\ \text{lbm}$$
$$m_{O2} = N_{O2} M_{O2} = (7\ \text{lbmol})(32\ \text{lbm/lbmol}) = 224\ \text{lbm}$$
$$m_{H2O} = N_{H2O} M_{H2O} = (28\ \text{lbmol})(18\ \text{lbm/lbmol}) = 504\ \text{lbm}$$
$$m_{CO2} = N_{CO2} M_{CO2} = (40\ \text{lbmol})(44\ \text{lbm/lbmol}) = 1760\ \text{lbm}$$

```
25% N₂
7% O₂
28% H₂O
40% CO₂
(by volume)
```

The total mass is

$$m_m = m_{N2} + m_{O2} + m_{H2O} + m_{CO2}$$
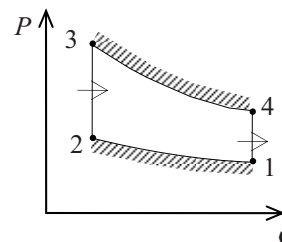$$= 700 + 224 + 504 + 1760$$
$$= 3188\ \text{lbm}$$

Then the mass fractions are

$$\text{mf}_{N2} = \frac{m_{N2}}{m_m} = \frac{700\ \text{lbm}}{3188\ \text{lbm}} = 0.2196$$

$$\text{mf}_{O2} = \frac{m_{O2}}{m_m} = \frac{224\ \text{lbm}}{3188\ \text{lbm}} = 0.07026$$

$$\text{mf}_{H2O} = \frac{m_{H2O}}{m_m} = \frac{504\ \text{lbm}}{3188\ \text{lbm}} = 0.1581$$

$$\text{mf}_{CO2} = \frac{m_{CO2}}{m_m} = \frac{1760\ \text{lbm}}{3188\ \text{lbm}} = 0.5521$$

The constant-pressure specific heat of the mixture is determined from

$$c_p = \text{mf}_{N2} c_{p,N2} + \text{mf}_{O2} c_{p,O2} + \text{mf}_{H2O} c_{p,H2O} + \text{mf}_{CO2} c_{p,CO2}$$
$$= 0.2196 \times 0.248 + 0.07026 \times 0.219 + 0.1581 \times 0.445 + 0.5521 \times 0.203$$
$$= 0.2523\ \text{Btu/lbm} \cdot \text{R}$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{3188\ \text{lbm}}{100\ \text{lbmol}} = 31.88\ \text{lbm/lbmol}$$

The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{1.9858\ \text{Btu/lbmol} \cdot \text{R}}{31.88\ \text{lbm/lbmol}} = 0.06229\ \text{Btu/lbm} \cdot \text{R}$$

Then the constant-volume specific heat is

$$c_v = c_p - R = 0.2523 - 0.06229 = 0.1900\ \text{Btu/lbm} \cdot \text{R}$$

The specific heat ratio is

$$k = \frac{c_p}{c_v} = \frac{0.2523}{0.1900} = 1.328$$

The average of the air properties at room temperature and combustion gas properties are

$$c_{p,avg} = 0.5(0.2523 + 0.240) = 0.2462 \text{ Btu/lbm} \cdot \text{R}$$

$$c_{v,avg} = 0.5(0.1900 + 0.171) = 0.1805 \text{ Btu/lbm} \cdot \text{R}$$

$$k_{avg} = 0.5(1.328 + 1.4) = 1.364$$

These average properties will be used for heat addition and rejection processes. For compression, the air properties at room temperature and during expansion, the mixture properties will be used. During the compression process,

$$T_2 = T_1 r^{k-1} = (515 \text{ R})(7)^{0.4} = 1122 \text{ R}$$

During the heat addition process,

$$q_{in} = c_{v,avg}(T_3 - T_2) = (0.1805 \text{ Btu/lbm} \cdot \text{R})(2060 - 1122) \text{ R} = 169.3 \text{ Btu/lbm}$$

During the expansion process,

$$T_4 = T_3 \left(\frac{1}{r}\right)^{k-1} = (2060 \text{ R})\left(\frac{1}{7}\right)^{0.364} = 1014 \text{ R}$$

During the heat rejection process,

$$q_{out} = c_{v,avg}(T_4 - T_1) = (0.1805 \text{ Btu/lbm} \cdot \text{R})(1014 - 515) \text{ R} = 90.1 \text{ Btu/lbm}$$

The thermal efficiency of the cycle is then

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{90.1 \text{ Btu/lbm}}{169.3 \text{ Btu/lbm}} = \mathbf{0.468}$$

The thermal efficiency of the standard air cycle is approximately 55%