CANKAYA UNIVERSITY
FACULTY OF ENGINEERING AND ARCHITECTURE
MECHANICAL ENGINEERING DEPARTMENT

ME 211 THERMODYNAMICS I
Fall 2015

CHAPTER 6 EXAMPLES SOLUTIONS

18) One-fifth kmol of carbon monoxide (CO) in a piston-cylinder assembly undergoes a process from p_1 =100 kPa, T_1 =298 K to p_2 =400 kPa, T_2 =360 K. For the process, W=-250 kJ. Employing the ideal gas model, determine
(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.

Solution

Solution:

(a) Write the energy balance equation as follows:

$$\Delta U + \Delta KE + \Delta PE = Q - W$$

Neglect the effect of motion and gravity that is take $\Delta KE = \Delta PE = 0$. Therefore,

$$\Delta U = Q - W$$

$$Q = \Delta U + W$$

$$= n\left[\bar{u}(T_2) - \bar{u}(T_1)\right] + W \qquad \ldots\ldots (1)$$

Take the following values from the table of ideal gas properties of carbon monoxide:

$$\bar{u}(T_1) = 6190 \text{ kJ/kmol}$$

$$\bar{u}(T_2) = 7480 \text{ kJ/kmol}$$

Substitute $\frac{1}{5}$ kmol for n, 6190 kJ/kmol for $\bar{u}(T_1)$, 7480 kJ/kmol for $\bar{u}(T_2)$ and -250 kJ for W in equation (1).

$$Q = \left(\frac{1}{5}\text{ kmol}\right)\left(7480 \text{ kJ/kmol} - 6190 \text{ kJ/kmol}\right) + \left(-250 \text{ kJ}\right)$$

$$= 8 \text{ kJ}$$

Thus, the heat transfer is $\boxed{8 \text{ kJ}}$.

(b) Use the following expression to determine the change in entropy:

$$\Delta S = n\left[\bar{s}^\circ(T_2) - \bar{s}^\circ(T_1) - \bar{R}\ln\left(\frac{p_2}{p_1}\right)\right] \qquad \ldots\ldots (2)$$

Take the following values from the table of ideal gas properties of carbon monoxide:

$$\bar{s}^\circ(T_1) = 197.543\ \text{kJ/kmol}\cdot\text{K}$$

$$\bar{s}^\circ(T_2) = 203.04\ \text{kJ/kmol}\cdot\text{K}$$

Substitute $\frac{1}{5}$ kmol for n, $197.543\ \text{kJ/kmol}\cdot\text{K}$ for $\bar{s}^\circ(T_1)$, $203.04\ \text{kJ/kmol}\cdot\text{K}$ for $\bar{s}^\circ(T_2)$, $8.314\ \text{kJ/kmol}\cdot\text{K}$ for $\bar{R}$, 100 kPa for p_1 and 400 kPa for p_2 in equation (2).

$$\begin{aligned}\Delta S &= \left(\frac{1}{5}\ \text{kmol}\right)\begin{bmatrix}203.04\ \text{kJ/kmol}\cdot\text{K} - 197.543\ \text{kJ/kmol}\cdot\text{K} \\ -(8.314\ \text{kJ/kmol}\cdot\text{K})\times\ln\left(\dfrac{400}{100}\right)\end{bmatrix} \\ &= -1.2057\ \text{kJ/K}\end{aligned}$$

Thus, there will be a change in entropy of $\boxed{-1.2057\ \text{kJ/K}}$.

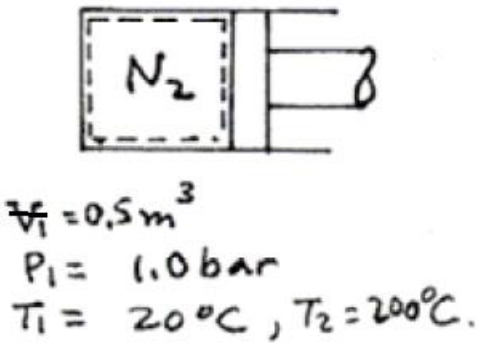
19) Nitrogen (N_2) initially occupying 0.5 m^3 at 1.0 bar, 20 °C, undergoes an internally reversible compression during which $pV^{1.3}$ =constant to a final state where the temperature is 200 °C. Assuming the ideal gas model, determine

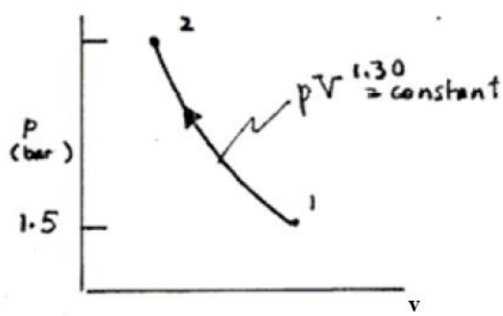
(a) the pressure at the final state, in bar.

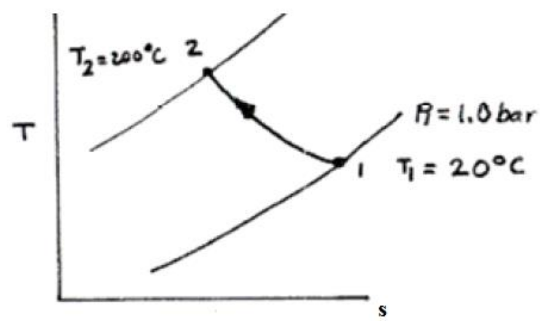
(b) the work and heat transfer, each in kJ.

(c) the entropy change, in kJ/K

Solution







Pressure is

$$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{n/(n-1)} = (1)\left(\frac{473}{293}\right)^{1.3/(1.3-1)} = 7.97\,\text{bar}$$

Mass is

$$m = \frac{p_1\forall_1}{RT_1} = \frac{(1\times10^5\ \text{N}/\text{m}^2)(0.5\,\text{m}^3)}{\dfrac{8314\dfrac{\text{N.m}}{\text{kmol.K}}}{28.01\dfrac{\text{kg}}{\text{kmol}}}.293\,\text{K}} = 0.5749\,\text{kg}$$

Work is

$$W = \int_1^2 p\,d\forall = \int_1^2 \frac{C}{\forall^n} d\forall = \frac{p_2\forall_2 - p_1\forall_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n} = \frac{(0.5749)\left(\frac{8.314}{28.01}\right)(473-293)}{1-1.3}$$

$$= -102.4\,\text{kJ}$$

$$Q = m(u_2 - u_1) + W$$

$$\text{at } T_2 = 473\,\text{K} \quad u_2 = 9849\,\text{kJ/kmol}$$

$$\text{at } T_1 = 293\,\text{K} \quad u_1 = 6083\,\text{kJ/kmol}$$

$$Q = (0.5749)(9849 - 6983)\left(\frac{\text{kJ}}{\text{kmol}}\right)\left(\frac{1\,\text{kmol}}{28.01\,\text{kg}}\right) + (-102.4\,\text{kJ}) = -25.1\,\text{kJ}$$

c) The entropy change

$$\Delta S = m[s_2 - s_1] = m\left[s_2^0 - s_1^0 - R\ln\left(\frac{p_2}{p_1}\right)\right]$$

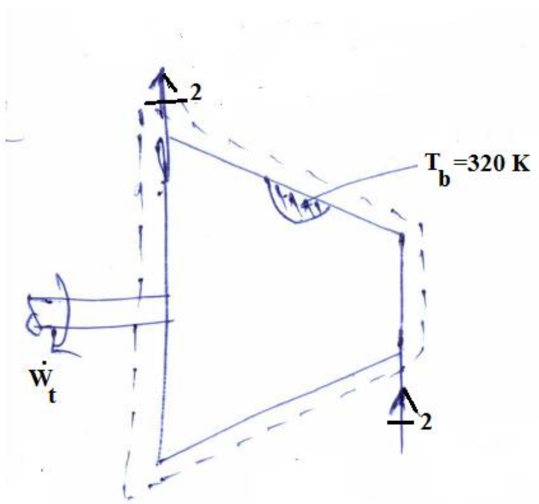
$$= (0.5749)\left[\frac{204.989 - 190.981}{28.01}\right] - \frac{8.314}{28.01}\ln\left(\frac{7.97}{1}\right) = -0.067\,\frac{\text{kJ}}{\text{K}}$$

20) Air at 500 kPa, 980 K enters a turbine operating at steady state and exits at 200 kPa, 680 K. Heat transfer from the turbine occurs at an average outer surface temperature of 320 K at the rate of 40 kJ per kg of air flowing. Kinetic and potential energy effects are negligible. For air as an ideal gas with c_p =1.5 kJ/kg.K, determine

(a) the rate of power developed, in kJ per kg of air flowing,

(b) the rate of entropy production within the turbine, in kJ/K per kg of air flowing.

Solution



$$\dot{Q}_{cv} - \dot{W}_{cv} = \dot{m}(h_2 - h_1)$$

or

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{\dot{Q}_{cv}}{\dot{m}} + (h_1 - h_2)$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{\dot{Q}_{cv}}{\dot{m}} + c_p(T_1 - T_2)$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = -40\frac{kJ}{kg} + 1.5\frac{kJ}{kg.K}(980 - 680)K = 410\frac{kJ}{kg}$$

b) Evaluate the entropy production

$$\sum_j \frac{\dot{Q}_j}{T_j} + \sum_j \dot{m}_i s_i - \sum_j \dot{m}_e s_e + \dot{\sigma}_{cv} = 0$$

$$\frac{\dot{Q}_{cv}}{T_b} + \dot{m}(s_1 - s_2) + \dot{\sigma}_{cv} = 0$$

Or

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{\dot{Q}_{cv}/\dot{m}}{T_b} + (s_2 - s_1)$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{\dot{Q}_{cv}/\dot{m}}{T_b} + \left[c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right)\right]$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -(-\frac{40\,\text{kJ/kg}}{320\,\text{K}}) + \left[1.5\frac{\text{kJ}}{\text{kg.K}}\ln\left(\frac{680}{960}\right) - \frac{8.314\frac{\text{kJ}}{\text{kmol.K}}}{28.97\frac{\text{kg}}{\text{kmol}}}\ln\left(\frac{200}{500}\right)\right]$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -0.160\frac{\text{kJ}}{\text{kg.K}}$$

21) A pump operating at steady state receives liquid water at 40°C, 1 MPa. The pressure of the water at the pump exit is 10 MPa. The magnitude of the work required by the pump is 15 kJ per kg of water flowing. Stray heat transfer and changes in kinetic and potential energy are negligible. Determine the isentropic pump efficiency.

Solution

There is no heat transfer that is $Q_{cv} = 0$. Neglect the effect of potential and kinetic energies and use the following expression to determine the work required to be done by the pump when it works reversibly:

$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{rev} = -v\left(p_2 - p_1\right)$$

Take the value of v from the table A-2 corresponding to saturated liquid at $40\,°\text{C}$ temperature.

$$v = v_f\left(40\,°\text{C}\right) = 1.0078 \times 10^{-3}\ \text{m}^3/\text{kg}$$

Substitute $1.0078 \times 10^{-3}\ \text{m}^3/\text{kg}$ for v, 1 MPa for p_1 and 10 MPa for p_2 in above expression of $\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{rev}$.

$$\begin{aligned}\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{rev} &= -\left(1.0078 \times 10^{-3}\ \text{m}^3/\text{kg}\right)\left(10\ \text{MPa} - 1\ \text{MPa}\right)\\ &= -\left(1.0078 \times 10^{-3}\ \text{m}^3/\text{kg}\right)\left(10 \times 10^6\ \text{N/m}^2 - 1 \times 10^6\ \text{N/m}^2\right)\left|\frac{1\ \text{kJ}}{10^3\ \text{N}\cdot\text{m}}\right|\\ &= -9.07\ \text{kJ/kg}\end{aligned}$$

Use the following expression to calculate isentropic efficiency of the pump:

$$\eta_{\text{pump}} = \frac{\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{rev}}{\frac{\dot{W}_{cv}}{\dot{m}}} = \frac{9.07\ \text{kJ/kg}}{12\ \text{kJ/kg}} = 0.7558 \text{ or } 75.58\%$$

Thus, the isentropic efficiency of the pump is $\boxed{75.58\%}$.