Homework #8 Solutions

#1 **4-63** The internal energy change of hydrogen gas during a heating process is to be determined using an empirical specific heat relation, constant specific heat at average temperature, and constant specific heat at room temperature.

Analysis (*a*) Using the empirical relation for $\bar{c}_p(T)$ from Table A-2c and relating it to $\bar{c}_v(T)$,

$$\bar{c}_v(T) = \bar{c}_p - R_u = (a - R_u) + bT + cT^2 + dT^3$$

where a = 29.11, b = -0.1916×10^{-2}, c = 0.4003×10^{-5}, and d = -0.8704×10^{-9}. Then,

$$\begin{aligned}
\Delta\bar{u} &= \int_1^2 \bar{c}_v(T)\,dT = \int_1^2 \left[(a - R_u) + bT + cT^2 + dT^3\right] dT \\
&= (a - R_u)(T_2 - T_1) + \tfrac{1}{2}b(T_2^2 + T_1^2) + \tfrac{1}{3}c(T_2^3 - T_1^3) + \tfrac{1}{4}d(T_2^4 - T_1^4) \\
&= (29.11 - 8.314)(800 - 200) - \tfrac{1}{2}(0.1961 \times 10^{-2})(800^2 - 200^2) \\
&\quad + \tfrac{1}{3}(0.4003 \times 10^{-5})(800^3 - 200^3) - \tfrac{1}{4}(0.8704 \times 10^{-9})(800^4 - 200^4) \\
&= 12{,}487 \text{ kJ/kmol}
\end{aligned}$$

$$\Delta u = \frac{\Delta\bar{u}}{M} = \frac{12{,}487 \text{ kJ/kmol}}{2.016 \text{ kg/kmol}} = \mathbf{6194\ kJ/kg}$$

(*b*) Using a constant c_p value from Table A-2b at the average temperature of 500 K,

$$c_{v,\text{avg}} = c_{v@500\text{ K}} = 10.389 \text{ kJ/kg}\cdot\text{K}$$

$$\Delta u = c_{v,\text{avg}}(T_2 - T_1) = (10.389 \text{ kJ/kg}\cdot\text{K})(800 - 200)\text{K} = \mathbf{6233\ kJ/kg}$$

(*c*) Using a constant c_p value from Table A-2a at room temperature,

$$c_{v,\text{avg}} = c_{v@300\text{ K}} = 10.183 \text{ kJ/kg}\cdot\text{K}$$

$$\Delta u = c_{v,\text{avg}}(T_2 - T_1) = (10.183 \text{ kJ/kg}\cdot\text{K})(800 - 200)\text{K} = \mathbf{6110\ kJ/kg}$$

#2 **4-120** The compression work from P_1 to P_2 using a polytropic process is to be compared for neon and air.

Assumptions The process is quasi-equilibrium.

Properties The gas constants for neon and air R = 0.4119 and 0.287 kJ/kg·K, respectively (Table A-2*a*).

Analysis For a polytropic process,

$$Pv^n = \text{Constant}$$

The boundary work during a polytropic process of an ideal gas is

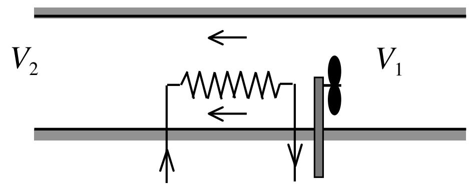
$$w_{b,\text{out}} = \int_1^2 P\,dv = \text{Constant}\int_1^2 v^{-n}\,dv = \frac{P_1 v_1}{1-n}\left[\left(\frac{v_2}{v_1}\right)^{1-n} - 1\right] = \frac{RT_1}{1-n}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

The negative of this expression gives the compression work during a polytropic process. Inspection of this equation reveals that the gas with the smallest gas constant (i.e., largest molecular weight) requires the least work for compression. In this problem, air will require the least amount of work.

#3 **5-10** Air is expanded and is accelerated as it is heated by a hair dryer of constant diameter. The percent increase in the velocity of air as it flows through the drier is to be determined.

Assumptions Flow through the nozzle is steady.

Properties The density of air is given to be 1.20 kg/m^3 at the inlet, and 1.05 kg/m^3 at the exit.

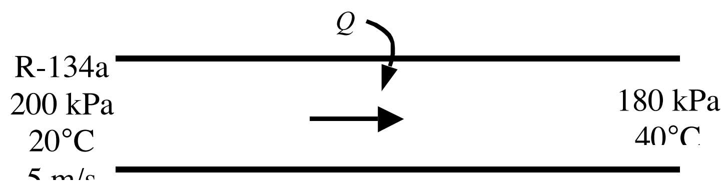


Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Then,

$$\dot{m}_1 = \dot{m}_2$$
$$\rho_1 A V_1 = \rho_2 A V_2$$
$$\frac{V_2}{V_1} = \frac{\rho_1}{\rho_2} = \frac{1.20 \text{ kg/m}^3}{1.05 \text{ kg/m}^3} = 1.14 \quad \text{(or, and increase of } \mathbf{14\%}\text{)}$$

Therefore, the air velocity increases 14% as it flows through the hair drier.

#4 **5-18** Refrigerant-134a flows through a pipe. Heat is supplied to R-134a. The volume flow rates of air at the inlet and exit, the mass flow rate, and the velocity at the exit are to be determined.



Properties The specific volumes of R-134a at the inlet and exit are (Table A-13)

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 20°\text{C} \end{array}\right\} v_1 = 0.1142 \text{ m}^3\text{/kg} \qquad \left.\begin{array}{l} P_1 = 180 \text{ kPa} \\ T_1 = 40°\text{C} \end{array}\right\} v_2 = 0.1374 \text{ m}^3\text{/kg}$$

Analysis (*a*) (*b*) The volume flow rate at the inlet and the mass flow rate are

$$\dot{V}_1 = A_c V_1 = \frac{\pi D^2}{4} V_1 = \frac{\pi (0.28 \text{ m})^2}{4} (5 \text{ m/s}) = \mathbf{0.3079 \text{ m}^3\text{/s}}$$

$$\dot{m} = \frac{1}{v_1} A_c V_1 = \frac{1}{v_1} \frac{\pi D^2}{4} V_1 = \frac{1}{0.1142 \text{ m}^3\text{/kg}} \frac{\pi (0.28 \text{ m})^2}{4} (5 \text{ m/s}) = \mathbf{2.696 \text{ kg/s}}$$

(c) Noting that mass flow rate is constant, the volume flow rate and the velocity at the exit of the pipe are determined from

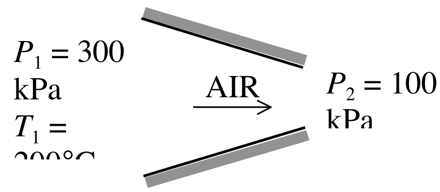
$$\dot{V}_2 = \dot{m} v_2 = (2.696 \text{ kg/s})(0.1374 \text{ m}^3\text{/kg}) = \mathbf{0.3705 \text{ m}^3\text{/s}}$$

$$V_2 = \frac{\dot{V}_2}{A_c} = \frac{0.3705 \text{ m}^3\text{/s}}{\frac{\pi (0.28 \text{ m})^2}{4}} = \mathbf{6.02 \text{ m/s}}$$

5. **5-31** Air is accelerated in a nozzle from 30 m/s to 180 m/s. The mass flow rate, the exit temperature, and the exit area of the nozzle are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with constant specific heats. **3** Potential energy changes are negligible. **4** The device is adiabatic and thus heat transfer is negligible. **5** There are no work interactions.

Properties The gas constant of air is 0.287 kPa.m^3/kg.K (Table A-1). The specific heat of air at the anticipated average temperature of 450 K is c_p = 1.02 kJ/kg.°C (Table A-2).



Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Using the ideal gas relation, the specific volume and the mass flow rate of air are determined to be

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(473\ \text{K})}{300\ \text{kPa}} = 0.4525\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_1}A_1V_1 = \frac{1}{0.4525\ \text{m}^3/\text{kg}}(0.008\ \text{m}^2)(30\ \text{m/s}) = \mathbf{0.5304\ kg/s}$$

(*b*) We take nozzle as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{Q} \cong \dot{W} \cong \Delta\text{pe} \cong 0)$$

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \quad \longrightarrow \quad 0 = c_{p,ave}(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}$$

Substituting, $$0 = (1.02\ \text{kJ/kg}\cdot\text{K})(T_2 - 200^\circ\text{C}) + \frac{(180\ \text{m/s})^2 - (30\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$

It yields T_2 = **184.6°C**

(*c*) The specific volume of air at the nozzle exit is

$$v_2 = \frac{RT_2}{P_2} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(184.6 + 273\ \text{K})}{100\ \text{kPa}} = 1.313\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_2}A_2V_2 \longrightarrow 0.5304\ \text{kg/s} = \frac{1}{1.313\ \text{m}^3/\text{kg}}A_2(180\ \text{m/s}) \rightarrow A_2 = 0.00387\ \text{m}^2 = \mathbf{38.7\ cm^2}$$