(a) Select and document the reference state used throughout your solution.
(b) What is the pressure and quantity (kg) of CO_2 in each cylinder?
(c) A cylinder marketed as specified needs to withstand warm temperatures in storage/ transport conditions. What is the minimum pressure that a full gas cylinder must withstand if it reaches 373 K?
(d) Consider the liquefaction process via compression of the CO_2 vapor from 80 °C, 1 bar to 6.5 MPa in a single adiabatic compressor ($\eta_C = 0.8$). The compressor is followed by cooling in a heat exchanger to 295 K and 6.5 MPa. Determine the process temperatures and pressures, the work and heat transfer requirement for each step, and the overall heat and work.
(e) Consider the liquefaction via compression of the CO_2 vapor from 80°C, 1 bar to 6.5 MPa in a two-stage compressor with interstage cooling. Each stage ($\eta_C = 0.8$) operates adiabatically. The interstage pressure is 2.5 MPa, and the interstage cooler returns the CO_2 temperature to 295 K. The two-stage compressor is followed by cooling in a heat exchanger to 295 K and 6.5 MPa. Determine all process temperatures and pressures, the work and heat transfer requirement for each step, and the overall heat and work.
(f) Calculate the minimum work required for the state change from 80°C, 1 bar to 295 K, 6.5 MPa with heat transfer to the surroundings at 295 K. What is the heat transfer required with the surroundings?

9.17 A three-cycle cascade refrigeration unit is to use methane (cycle 1), ethylene (cycle 2), and ammonia (cycle 3). The evaporators are to operate at: cycle 1, 115.6 K; cycle 2, 180 K; cycle 3, 250 K. The outlets of the compressors are to be: cycle 1, 4 MPa; cycle 2, 2.6 MPa; cycle 3, 1.4 MPa. Use the Peng-Robinson equation to estimate fluid properties. Use stream numbers from Fig. 5.11 on page 212. The compressors have efficiencies of 80%.

(a) Determine the flow rate for cycle 2 and cycle 3 relative to the flow rate in cycle 1.
(b) Determine the work required in each compressor per kg of fluid in the cycle.
(c) Determine the condenser duty in cycle 3 per kg of flow in cycle 1.
(d) Suggest two ways that the cycle could be improved.

9.18 Consider the equation of state

$$Z = 1 + \frac{4c\eta_p}{1 - 1.9\eta_p} - \frac{a\eta_p}{bRT}$$

where $\eta_p = b/V$.

(a) Determine the relationships between a, b, c and T_c, P_c, Z_c.
(b) What practical restrictions are there on the values of Z_c that can be modeled with this equation?
(c) Derive an expression for the fugacity.
(d) Modify Preos.xlsx or Preos.m for this equation of state. Determine the value of c (+/– 0.5) that best represents the vapor pressure of the specified compound below. Use the shortcut vapor pressure equation to estimate the experimental vapor pressure for the purposes of this problem for the option(s) specifed by your instructor.

(i) CO_2
(ii) Ethane
(iii) Ethylene
(iv) Propane
(v) *n*-Hexane