Thermodynamics and energetics I: Exercise 4

The exercise deals with thermodynamic cycles and application of the 1st law to calculate work and heat transfer in systems using ideal gas substances.

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1. A gas mixture with molar weight of 33 kg/kmol is considered. Initial condition is $p = 3$ bar, $T = 300$ K, $V = 0.1$ m^3. The gas is expanded up to a volume of 0.2 m^3. During the expansion $pV^{1.3} = \text{const}$. Neglect kinetic and potential effects and assume an ideal gas and $c_\text{v} = 0.6 + (2.5 \cdot 10^{-4}) \cdot T$, where T is in K and c_v in kJ/(kg $\cdot$ K).

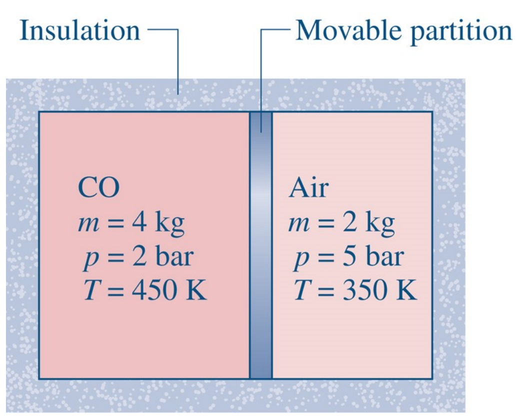
   Determine

   (a) the mass of the gas.
   (b) the end pressure of the gas.
   (c) the end temperature of the gas.
   (d) the work and heat transfer.

2. 2 kg of air, initially at 5 bar and 350 K, and 4 kg of carbon monoxide (CO), initially at 2 bar and 450 K, are confined to opposite sides of a rigid, well-insulated container by a partition. The partition is free to move without any friction and allows heat conduction from one gas to the other without energy storage in the partition itself. Both air and CO behave as perfect gases with constant specific heat ratio, $k = 1.395$.

   Determine at equilibrium

   (a) the temperature in each side of the container.
   (b) the pressure in each side of the container.
   (c) the volume occupied by each gas.



3. Inside a piston-cylinder system, hydrogen has volume $V_1 = 1\ \text{m}^3$, pressure $p_1 = 100$ kPa, temperature $T_1 = 300$ K. A spring is attached to the piston without applying any force in the initial state. The spring force is described by $F = -k \cdot x$, with the spring constant $k = 30$ kN/m. The minus sign indicates that the force is in the opposite direction to the change in spring position. The piston surface area is 0.8 m^2. Heat is transferred to the hydrogen leading to an expansion of the volume by a factor of 2. The environmental pressure is 100 kPa. Assume hydrogen behaves like perfect gas with $c_v = 10.4$ kJ/K/kg.

   (a) Determine the mass, final temperature and final pressure.

   (b) Determine the total work supplied by the system.

   (c) Determine the fraction of work that is supplied against the spring.

   (d) Determine the heat transfer to the system in order to allow for the expansion.

   (e) Draw the process in the p-V diagram.

4. A rigid tank initially contains 3 kg of carbon dioxide (CO_2) at 500 kPa. The tank is connected by a valve to a piston-cylinder assembly located vertically above, initially containing 0.05 m^3 of CO_2. Although the valve is closed, a slow leak allows CO_2 to flow into the cylinder from the tank until the tank pressure falls to 200 kPa. The weight of the piston and the pressure of the atmosphere maintain a constant pressure of 200 kPa in the cylinder. Owing to heat transfer, the temperature of the CO_2 throughout the tank and cylinder stays constant at 290 K. Assuming ideal gas behavior, determine for the CO_2 the work and heat transfer.