6-173 CD EES An insulated cylinder equipped with an external spring initially contains air. The tank is connected to a supply line, and air is allowed to enter the cylinder until its volume doubles. The mass of the air that entered and the final temperature in the cylinder are to be determined.

Assumptions **1** This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid at the inlet remains constant. **2** The expansion process is quasi-equilibrium. **3** Kinetic and potential energies are negligible. **4** The spring is a linear spring. **5** The device is insulated and thus heat transfer is negligible. **6** Air is an ideal gas with constant specific heats.

Properties The gas constant of air is $R = 0.287$ kJ/kg·K (Table A-1). The specific heats of air at room temperature are $c_v = 0.718$ and $c_p = 1.005$ kJ/kg·K (Table A-2a). Also, $u = c_v T$ and $h = c_p T$.

Analysis We take the cylinder as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy h and internal energy u, respectively, the mass and energy balances for this uniform-flow system can be expressed as
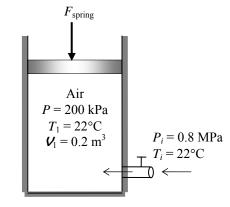
F_{spring}

Air
$P = 200$ kPa
$T_1 = 22°C$
$V_1 = 0.2$ m³

$P_i = 0.8$ MPa
$T_i = 22°C$

Mass balance:

$$m_{in} - m_{out} = \Delta m_{system} \rightarrow m_i = m_2 - m_1$$

Energy balance:

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$m_i h_i = W_{b,out} + m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong \text{ke} \cong \text{pe} \cong 0)$$

Combining the two relations, $\left(m_2 - m_1\right)h_i = W_{b,out} + m_2 u_2 - m_1 u_1$

or, $\left(m_2 - m_1\right)c_p T_i = W_{b,out} + m_2 c_v T_2 - m_1 c_v T_1$

The initial and the final masses in the tank are

$$m_1 = \frac{P_1 V_1}{RT_1} = \frac{(200 \text{ kPa})(0.2 \text{ m}^3)}{(0.287 \text{ kPa·m}^3/\text{kg·K})(295 \text{ K})} = 0.472 \text{ kg}$$

$$m_2 = \frac{P_2 V_2}{RT_2} = \frac{(600 \text{ kPa})(0.4 \text{ m}^3)}{(0.287 \text{ kPa·m}^3/\text{kg·K})T_2} = \frac{836.2}{T_2}$$

Then from the mass balance becomes $m_i = m_2 - m_1 = \dfrac{836.2}{T_2} - 0.472$

The spring is a linear spring, and thus the boundary work for this process can be determined from

$$W_b = \text{Area} = \frac{P_1 + P_2}{2}(V_2 - V_1) = \frac{(200 + 600)\text{kPa}}{2}(0.4 - 0.2)\text{m}^3 = 80 \text{ kJ}$$

Substituting into the energy balance, the final temperature of air T_2 is determined to be

$$-80 = -\left(\frac{836.2}{T_2} - 0.472\right)(1.005)(295) + \left(\frac{836.2}{T_2}\right)(0.718)(T_2) - (0.472)(0.718)(295)$$

It yields $T_2 = $ **344.1 K**

Thus, $m_2 = \dfrac{836.2}{T_2} = \dfrac{836.2}{344.1} = 2.430 \text{ kg}$

and $m_i = m_2 - m_1 = 2.430 - 0.472 = $ **1.96 kg**