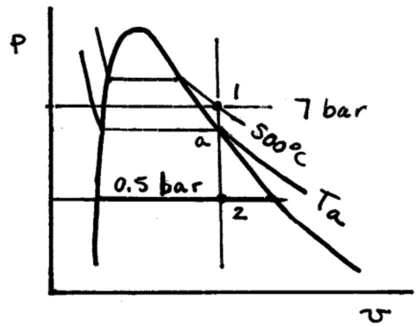
Problem 2

KNOWN: Steam is cooled in a closed rigid container from a known initial state to a known final pressure.

FIND: Determine the temperature at which condensation first occurs, the fraction of the total mass that condenses, and the volume occupied by saturated liquid at the final state.

SCHEMATIC & GIVEN DATA:

$P_1 = 7$ bar
$T_1 = 500°C$
$V = 1\ m^3$



ASSUMPTIONS: (1) The steam is a closed system. (2) The volume is constant.

ANALYSIS: By assumptions (1) and (2), the specific volume is constant. Thus, using data from Table A-4

$$v_1 = v_a = v_2 = 0.5070\ m^3/kg$$

Then from Table A-2

$$T_a = T_{sat}@\ v_a = 140°C \longleftarrow T_a$$

Next, the fraction of the total mass that condenses is

$$\text{fraction condensed} = \frac{m_{f2}}{m} = 1 - x_2$$

$$x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}} = \frac{0.5070 - 1.0300 \times 10^{-3}}{3.420 - 1.0300 \times 10^{-3}} = 0.1480$$

Thus

$$\text{fraction condensed} = 1 - 0.1480 = 0.8520 \longleftarrow$$

The total mass of the system is $m = \frac{V}{v_1} = \frac{(1\ m^3)}{(0.5070\ m^3/kg)}$

$$= 1.972\ kg$$

Then, the volume of the liquid at state 2 is

$$V_{f2} = m\, v_{f2} = (1.972\ kg)(1.0300 \times 10^{-3}\ m^3/kg)$$

$$V_{f2} = 0.00203\ m^3 \longleftarrow V_{f2}$$

Problem 3

ASSUMPTIONS: 1. The closed system is shown by a dashed line on the above schematic. 2. The gas behaves as an ideal gas. 3. For the process, $Q = W = 0$, and kinetic and potential energy changes are neglibible.

Applying the ideal gas equation of state

$$\left.\begin{array}{l} P_1 V_1 = mRT_1 \\ P_2 V_2 = mRT_2 \end{array}\right\rangle \quad \frac{P_2 V_2}{P_1 V_1} = \frac{T_2}{T_1} \Rightarrow P_2 = P_1\left[\frac{T_2}{T_1}\right]\left[\frac{V_1}{V_2}\right]$$

The final temperature is required. Applying an energy balance

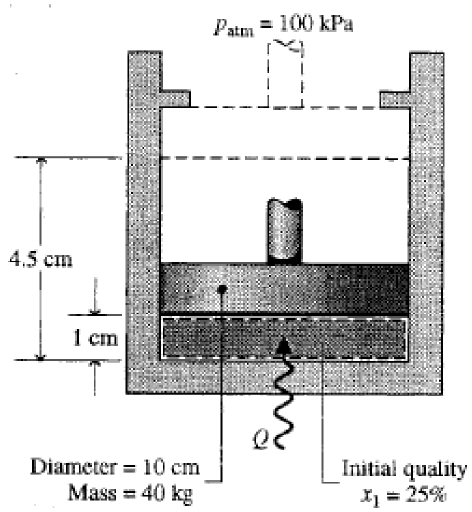
$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = \cancel{Q} - \cancel{W} \Rightarrow \Delta U = 0$$

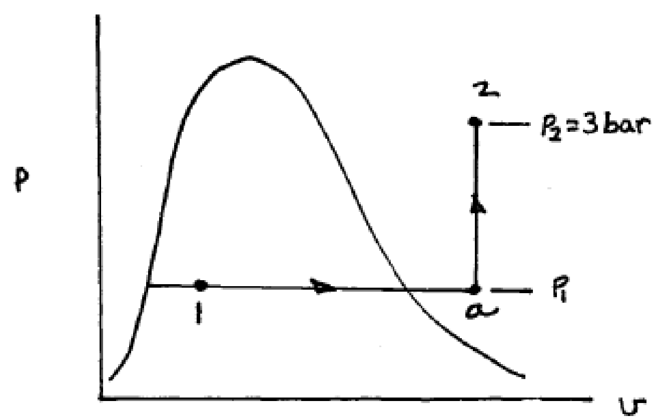
Since internal energy of an ideal gas depends on temperature alone, $T_2 = T_1$. Thus

$$P_2 = (5\text{ bar})\left[1\right]\left[\frac{0.2\text{ m}^3}{0.5\text{ m}^3}\right] = 2\text{ bar}$$

Problem 4

SCHEMATIC & GIVEN DATA:





ASSUMPTIONS: 1. The water is a closed system. 2. The pressure is constant until the piston hits the stops. 3. Friction between the piston and cylinder wall can be ignored. 4. For the system, ΔPE, ΔKE can be ignored. 5. g is constant.

To begin, fix the three states located by dots on the p-v diagram. State 1 is fixed by $x_1 = 25\%$ and p_1, which is found from a force balance on the piston: The force exerted by the water on the lower face of the piston equals the piston weight plus the force exerted on the top face by the atmosphere:

$$p_1 A = m_{pist}\, g + p_{atm} A \quad , \; A = \pi D_{pist}^2 / 4$$

$$\Rightarrow \quad p_1 = \frac{m_{pist}\, g}{A} + p_{atm} = \frac{(40\text{ kg})(9.81\text{ m/s}^2)}{\frac{\pi}{4}(0.1\text{ m})^2}\left|\frac{1\text{ N}}{\text{kg}\cdot\text{m/s}^2}\right|\left|\frac{\text{bar}}{10^5\text{ N/m}^2}\right| + (100\text{ kPa})\left|\frac{1\text{ bar}}{10^2\text{ kPa}}\right|$$

$$= 1.5\text{ bar}$$

State a is fixed by $p_a = p_1 = 1.5$ bar and the specific volume, v_a. From the given geometry, $V_a = 4.5 V_1$ or $v_a = 4.5 v_1$, where

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1}) = \frac{1.0528}{10^3} + 0.25\left(1.159 - \frac{1.0528}{10^3}\right) = 0.29054\text{ m}^3/\text{kg}$$

$$\rightarrow \quad v_a = 4.5(0.29054) = 1.3074\text{ m}^3/\text{kg}$$

Since $v_a > v_g(1.5\text{ bar})$, state a falls in the superheated vapor region, as shown in the p-v diagram. State 3 is fixed by $v_2 = v_a$ and $p_2 = 3$ bar.

The total mass of water is

$$m = \frac{V}{v_1} = \frac{\pi/4\,(0.1\text{ m})^2(0.01\text{ m})}{0.29054\text{ m}^3/\text{kg}} = 2.703\times10^{-4}\text{ kg}$$

Since there is no work associated with the constant volume portion of the process, the total work is obtained as the water undergoes the constant pressure expansion from 1 to a:

$$W = \int_1^a p\,dV = p[V_a - V_1] = p[V_2 - V_1] = mp(v_2 - v_1)$$

That is, with $v_2 = 4.5 v_1$

$$W = (2.703\times10^{-4}\text{ kg})(1.5\text{ bar})\left|\frac{10^5\text{ N/m}^2}{1\text{ bar}}\right|(3.5)\left(0.29054\frac{\text{m}^3}{\text{kg}}\right)\left|\frac{1\text{ J}}{1\text{ N}\cdot\text{m}}\right|$$

$$= 41.23\text{ J} \longleftarrow$$

An energy balance reads

$$\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - W$$

$$\Rightarrow \quad Q = \Delta U + W$$

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

where

$$u_1 = u_{f1} + x_1 (u_{g1} - u_{f1})$$

$$= 466.94 + 0.25(2519.7 - 466.94) = 980.13 \ kJ/kg$$

To find u_2, interpolate at 3 bar using v_2: $u_2 = 3263.53$

Then

$$Q = (2.703 \times 10^{-4} \ kg)(3263.53 - 980.13) \frac{kJ}{kg} \left| \frac{10^3 J}{kJ} \right| + 41.23 \ J$$

$$= 658.43 \ J$$