5.50

A water-filled reactor with volume of 1 m^3 is at 20 MPa, 360°C and placed inside a containment room as shown in Fig. P5.50. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the minimum room volume so the final pressure does not exceed 200 kPa.

Solution:

C.V.: Containment room and reactor.

Mass: $m_2 = m_1 = V_{reactor}/v_1 = 1/0.001823 = 548.5$ kg

Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0 - 0 = 0$

State 1: Table B.1.4 $v_1 = 0.001823$ m^3/kg, $u_1 = 1702.8$ kJ/kg

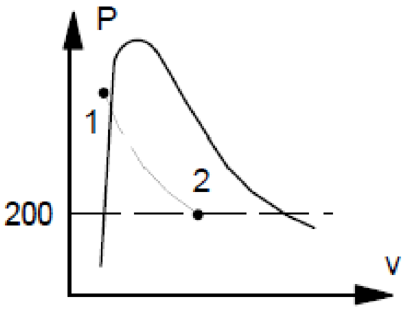
Energy equation then gives $u_2 = u_1 = 1702.8$ kJ/kg

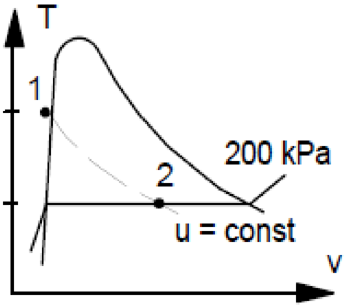
State 2: $P_2 = 200$ kPa, $u_2 < u_g$ => Two-phase Table B.1.2

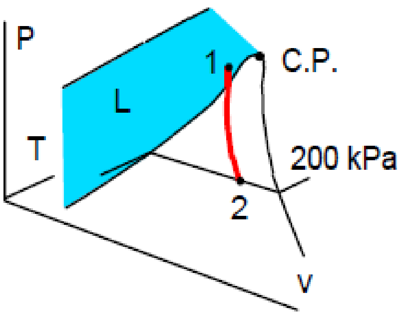
$x_2 = (u_2 - u_f)/ u_{fg} = (1702.8 – 504.47)/2025.02 = 0.59176$

$v_2 = 0.001061 + 0.59176 \times 0.88467 = 0.52457$ m^3/kg

$V_2 = m_2 v_2 = 548.5 \times 0.52457 = 287.7$ m^3







5.66

A piston cylinder has a water volume separated in $V_A = 0.2$ m^3 and $V_B = 0.3$ m^3 by a stiff membrane. The initial state in A is 1000 kPa, x = 0.75 and in B it is 1600 kPa and 250°C. Now the membrane ruptures and the water comes to a uniform state at 200°C. What is the final pressure? Find the work and the heat transfer in the process.

Take the water in A and B as CV.

Continuity: $m_2 - m_{1A} - m_{1B} = 0$

Energy: $m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} = {}_1Q_2 - {}_1W_2$

Process: $P_2 = P_{eq} = \text{constant} = P_{1A}$ as piston floats and m_p, P_o do not change

State 1A: Two phase. Table B.1.2

$v_{1A} = 0.001127 + 0.75 \times 0.19332 = 0.146117$ m^3/kg,

$u_{1A} = 761.67 + 0.75 \times 1821.97 = 2128.15$ kJ/kg

State 1B: Table B.1.3 $v_{1B} = 0.14184$ m^3/kg, $u_{1B} = 2692.26$ kJ/kg

=> $m_{1A} = V_{1A}/v_{1A} = 1.3688$ kg, $m_{1B} = V_{1B}/v_{1B} = 2.115$ kg

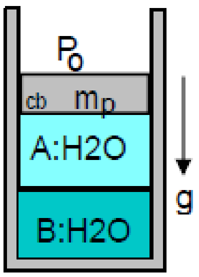
State 2: 1000 kPa, 200°C sup. vapor => $v_2 = 0.20596$ m^3/kg, $u_2 = 2621.9$ kJ/kg

$m_2 = m_{1A} + m_{1B} = 3.4838$ kg => $V_2 = m_2v_2 = 3.4838 \times 0.20596 = 0.7175$ m^3

So now

$${}_1W_2 = \int P\, dV = P_{eq}(V_2 - V_1) = 1000\ (0.7175 - 0.5) = 217.5 \text{ kJ}$$

$${}_1Q_2 = m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} + {}_1W_2$$
$$= 3.4838 \times 2621.9 - 1.3688 \times 2128.15 - 2.115 \times 2692.26 + 217.5 = 744 \text{ kJ}$$



5.75

A rigid tank A of volume 0.6 m^3 contains 3 kg water at 120°C and the rigid tank B is 0.4 m^3 with water at 600 kPa, 200°C. They are connected to a piston cylinder initially empty with closed valves. The pressure in the cylinder should be 800 kPa to float the piston. Now the valves are slowly opened and heat is transferred so the water reaches a uniform state at 250°C with the valves open. Find the final volume and pressure and the work and heat transfer in the process.

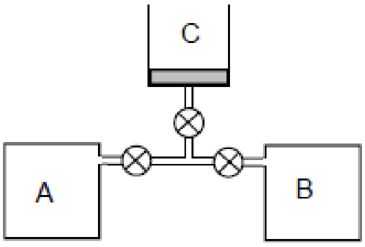
C.V.: A + B + C.

Only work in C, total mass constant.

$m_2 - m_1 = 0 \quad => \quad m_2 = m_{A1} + m_{B1}$

$U_2 - U_1 = {}_1Q_2 - {}_1W_2$;

${}_1W_2 = \int PdV = P_{lift}(V_2 - V_1)$



1A: $v = 0.6/3 = 0.2\ m^3/kg \quad => \quad x_{A1} = (0.2 - 0.00106)/0.8908 = 0.223327$

$u = 503.48 + 0.223327 \times 2025.76 = 955.89$ kJ/kg

1B: $v = 0.35202\ m^3/kg \quad => \quad m_{B1} = 0.4/0.35202 = 1.1363$ kg ; $u = 2638.91$ kJ/kg

$m_2 = 3 + 1.1363 = 4.1363$ kg and

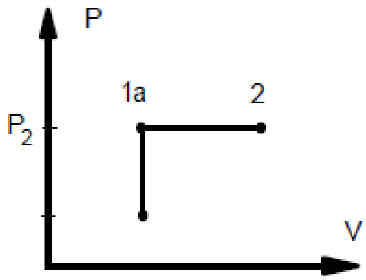
$V_2 = V_A + V_B + V_C = 1 + V_C$

Locate state 2: Must be on P-V lines shown

State 1a: 800 kPa,

$$v_{1a} = \frac{V_A + V_B}{m} = 0.24176\ m^3/kg$$

800 kPa, v_{1a} => T = 173°C too low.



Assume 800 kPa: 250°C => $v = 0.29314\ m^3/kg > v_{1a}$ OK

$V_2 = m_2 v_2 = 4.1363\ kg \times 0.29314\ m^3/kg = 1.21\ m^3$

Final state is : 800 kPa; 250°C => $u_2 = 2715.46$ kJ/kg

$W = 800(0.29314 - 0.24176) \times 4.1363 = 800 \times (1.2125 - 1) = 170$ kJ

$Q = m_2u_2 - m_1u_1 + {}_1W_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2$

$= 4.1363 \times 2715.46 - 3 \times 955.89 - 1.1363 \times 2638.91 + 170$

$= 11\ 232 - 2867.7 - 2998.6 + 170 = 5536$ kJ

5.89

An engine consists of a 100 kg cast iron block with a 20 kg aluminum head, 20 kg steel parts, 5 kg engine oil and 6 kg glycerine (antifreeze). Everything begins at 5°C and as the engine starts we want to know how hot it becomes if it absorbs a net of 7000 kJ before it reaches a steady uniform temperature.

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Process: The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

So sum over the various parts of the left hand side in the energy equation

$$m_{Fe}\,(u_2 - u_1) + m_{Al}\,(u_2 - u_1)_{Al} + m_{st}\,(u - u_1)_{st} + m_{oil}\,(u_2 - u_1)_{oil} + m_{gly}\,(u_2 - u_1)_{gly} = {}_1Q_2$$

Table A.3 : $C_{Fe} = 0.42$, $C_{Al} = 0.9$, $C_{st} = 0.46$ all units of kJ/kg K

Table A.4 : $C_{oil} = 1.9$, $C_{gly} = 2.42$ all units of kJ/kg K

So now we factor out $T_2 - T_1$ as $u_2 - u_1 = C(T_2 - T_1)$ for each term

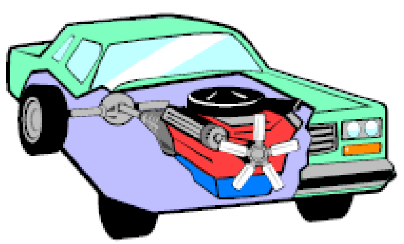
$$[\, m_{Fe}C_{Fe} + m_{Al}C_{Al} + m_{st}C_{st} + m_{oil}C_{oil} + m_{gly}C_{gly} \,]\,(T_2 - T_1) = {}_1Q_2$$

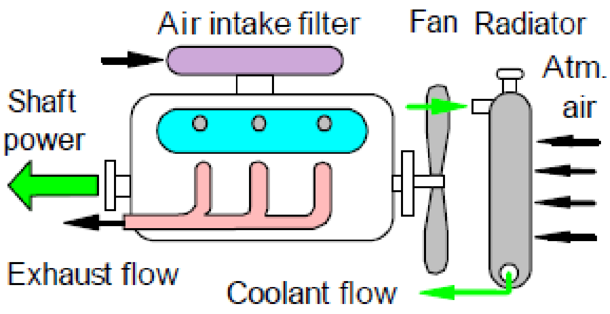
$$T_2 - T_1 = {}_1Q_2 / \Sigma m_i\, C_i$$

$$= \frac{7000}{100\times 0.42 + 20\times 0.9 + 20\times 0.46 + 5\times 1.9 + 6\times 2.42}$$

$$= \frac{7000}{93.22} = 75\text{ K}$$

$$T_2 = T_1 + 75 = 5 + 75 = 80^{\circ}\text{C}$$





5.119

Air in a piston/cylinder at 200 kPa, 600 K, is expanded in a constant-pressure process to twice the initial volume (state 2), shown in Fig. P5.101. The piston is then locked with a pin and heat is transferred to a final temperature of 600 K. Find *P*, *T*, and *h* for states 2 and 3, and find the work and heat transfer in both processes.

Solution:

C.V. Air. Control mass $m_2 = m_3 = m_1$

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$;

Process 1 to 2: P = constant => ${}_1w_2 = \int P\,dv = P_1(v_2 - v_1) = R(T_2 - T_1)$

Ideal gas $Pv = RT \Rightarrow T_2 = T_1 v_2/v_1 = 2T_1 = 1200$ K

$P_2 = P_1 = 200$ kPa, ${}_1w_2 = RT_1 = 172.2$ kJ/kg

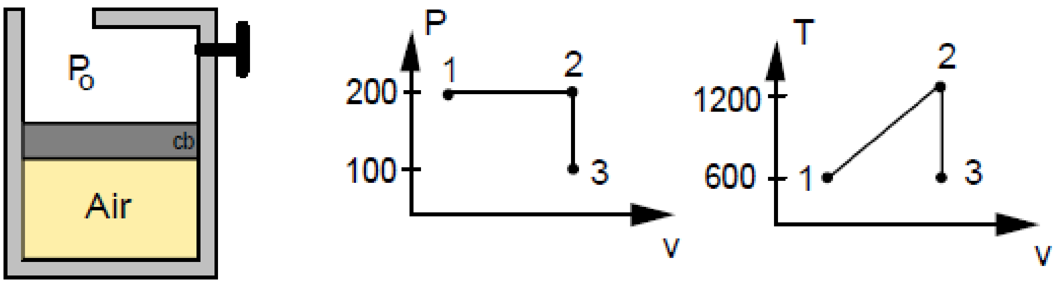
Table A.7 $h_2 = 1277.8$ kJ/kg, $h_3 = h_1 = 607.3$ kJ/kg

${}_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1 = 1277.8 - 607.3 = 670.5$ kJ/kg

Process 2→3: $v_3 = v_2 = 2v_1 \Rightarrow {}_2w_3 = 0$,

$P_3 = P_2T_3/T_2 = P_1T_1/2T_1 = P_1/2 = 100$ kPa

${}_2q_3 = u_3 - u_2 = 435.1 - 933.4 = -498.3$ kJ/kg



5.134

An air pistol contains compressed air in a small cylinder, shown in Fig. P5.134. Assume that the volume is 1 cm^3, pressure is 1 MPa, and the temperature is 27°C when armed. A bullet, $m = 15$ g, acts as a piston initially held by a pin (trigger); when released, the air expands in an isothermal process ($T =$ constant). If the air pressure is 0.1 MPa in the cylinder as the bullet leaves the gun, find

a. The final volume and the mass of air.

b. The work done by the air and work done on the atmosphere.

c. The work to the bullet and the bullet exit velocity.

Solution:

C.V. Air.

Air ideal gas: $m_{air} = P_1V_1/RT_1 = 1000 \times 10^{-6}/(0.287 \times 300) = 1.17 \times 10^{-5}$ kg

Process: $PV = \text{const} = P_1V_1 = P_2V_2 \Rightarrow V_2 = V_1P_1/P_2 = 10\ cm^3$

$${}_1W_2 = \int P dV = \int \frac{P_1V_1}{V} dV = P_1V_1 \ln (V_2/V_1) = 2.303 \text{ J}$$

$${}_1W_{2,ATM} = P_0(V_2 - V_1) = 101 \times (10 - 1) \times 10^{-6} \text{ kJ} = 0.909 \text{ J}$$

$$W_{bullet} = {}_1W_2 - {}_1W_{2,ATM} = 1.394 \text{ J} = \frac{1}{2} m_{bullet}(V_{exit})^2$$

$$V_{exit} = (2W_{bullet}/m_B)^{1/2} = (2 \times 1.394/0.015)^{1/2} = 13.63 \text{ m/s}$$

5.165

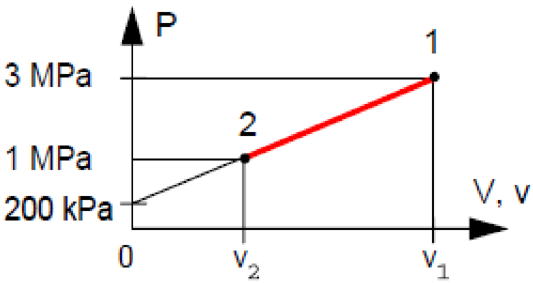
A piston/cylinder arrangement has a linear spring and the outside atmosphere acting on the piston, shown in Fig. P5.165. It contains water at 3 MPa, 400°C with the volume being 0.1 m^3. If the piston is at the bottom, the spring exerts a force such that a pressure of 200 kPa inside is required to balance the forces. The system now cools until the pressure reaches 1 MPa. Find the heat transfer for the process.

Solution:

C.V. Water.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$



State 1: Table B.1.3

$v_1 = 0.09936\ m^3/kg$, $u_1 = 2932.8$ kJ/kg

$m = V/v_1 = 0.1/0.09936 = 1.006$ kg

Process: Linear spring so P linear in v.

$$P = P_0 + (P_1 - P_0)v/v_1$$

$$v_2 = \frac{(P_2 - P_0)v_1}{P_1 - P_0} = \frac{(1000 - 200)0.09936}{3000 - 200} = 0.02839\ m^3/kg$$

State 2: $P_2, v_2 \Rightarrow x_2 = (v_2 - 0.001127)/0.19332 = 0.141$, $T_2 = 179.91°C$,

$u_2 = 761.62 + x_2 \times 1821.97 = 1018.58$ kJ/kg

Process => $_1W_2 = \int PdV = \frac{1}{2}m(P_1 + P_2)(v_2 - v_1)$

$$= \frac{1}{2} 1.006\ (3000 + 1000)(0.02839 - 0.09936) = -142.79\ kJ$$

Heat transfer from the energy equation

$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.006(1018.58 - 2932.8) - 142.79 = -2068.5$ kJ