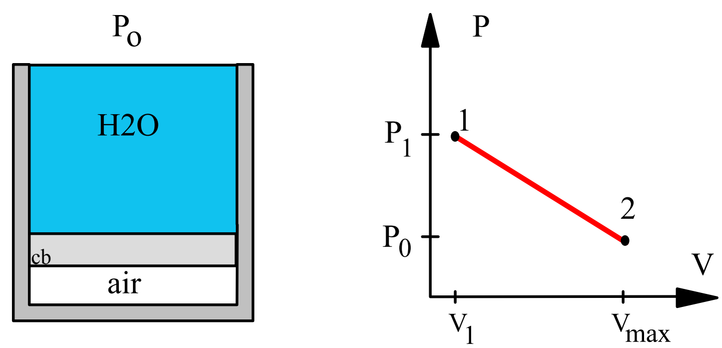
5.93

A 10-m high cylinder, cross-sectional area 0.1 m^2, has a massless piston at the bottom with water at 20°C on top of it, shown in Fig. P5.93. Air at 300 K, volume 0.3 m^3, under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air when all the water has been pushed out.

Solution:



The water on top is compressed liquid and has volume and mass

$$V_{H_2O} = V_{tot} - V_{air} = 10 \times 0.1 - 0.3 = 0.7 \text{ m}^3$$

$$m_{H_2O} = V_{H_2O}/v_f = 0.7 / 0.001002 = 698.6 \text{ kg}$$

The initial air pressure is then

$$P_1 = P_0 + m_{H_2O}g/A = 101.325 + \frac{698.6 \times 9.807}{0.1 \times 1000} = \mathbf{169.84 \text{ kPa}}$$

and then $m_{air} = PV/RT = \dfrac{169.84 \times 0.3}{0.287 \times 300} = 0.592$ kg

State 2: No liquid water over the piston so

$$P_2 = P_0 + \emptyset = 101.325 \text{ kPa}, \quad V_2 = 10{\times}0.1 = 1 \text{ m}^3$$

State 2: P_2, V_2 $\Rightarrow$ $T_2 = \dfrac{T_1P_2V_2}{P_1V_1} = \dfrac{300{\times}101.325{\times}1}{169.84{\times}0.3} = 596.59$ K

The process line shows the work as an area

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) = \frac{1}{2}(169.84 + 101.325)(1 - 0.3) = 94.91 \text{ kJ}$$

The energy equation solved for the heat transfer becomes

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.592 \times 0.717 \times (596.59 - 300) + 94.91 = \mathbf{220.7 \text{ kJ}}$$

Remark: we could have used u values from Table A.7:

$u_2 - u_1 = 432.5 - 214.36 = 218.14$ kJ/kg versus 212.5 kJ/kg with C_v.

6.131

A steam engine based on a turbine is shown in Fig. P6.131. The boiler tank has a volume of 100 L and initially contains saturated liquid with a very small amount of vapor at 100 kPa. Heat is now added by the burner, and the pressure regulator does not open before the boiler pressure reaches 700 kPa, which it keeps constant. The saturated vapor enters the turbine at 700 kPa and is discharged to the atmosphere as saturated vapor at 100 kPa. The burner is turned off when no more liquid is present in the as boiler. Find the total turbine work and the total heat transfer to the boiler for this process.

Solution:

C.V. Boiler tank. Heat transfer, no work and flow out.

Continuity Eq.6.15: $m_2 - m_1 = - m_e$

Energy Eq.6.16: $m_2u_2 - m_1u_1 = Q_{CV} - m_eh_e$

State 1: Table B.1.1, 100 kPa => $v_1 = 0.001\ 043$, $u_1 = 417.36$ kJ/kg

=> $m_1 = V/v_1 = 0.1/0.001\ 043 = 95.877$ kg

State 2: Table B.1.1, 700 kPa => $v_2 = v_g = 0.2729$, $u_2 = 2572.5$ kJ/kg

=> $m_2 = V/v_g = 0.1/0.2729 = 0.366$ kg,

Exit state: Table B.1.1, 700 kPa => $h_e = 2763.5$ kJ/kg

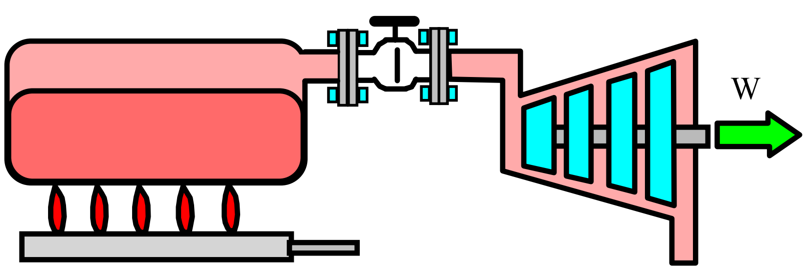
From continuity eq.: $m_e = m_1 - m_2 = 95.511$ kg

$$Q_{CV} = m_2u_2 - m_1u_1 + m_eh_e$$
$$= 0.366 \times 2572.5 - 95.877 \times 417.36 + 95.511 \times 2763.5$$
$$= 224\ 871 \text{ kJ} = \mathbf{224.9\ MJ}$$

C.V. Turbine, steady state, inlet state is boiler tank exit state.

Turbine exit state: Table B.1.1, 100 kPa => $h_e = 2675.5$ kJ/kg

$$W_{turb} = m_e\,(h_{in} - h_{ex}) = 95.511 \times (2763.5 - 2675.5) = \mathbf{8405\ kJ}$$



Problem 5

4-145 An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states. The final equilibrium temperature in the cylinder when thermal equilibrium is established is to be determined for the cases of the piston being fixed and moving freely.

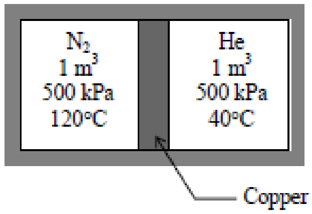
Assumptions **1** Both N_2 and He are ideal gases with constant specific heats. **2** The energy stored in the container itself, except the piston, is negligible. **3** The cylinder is well-insulated and thus heat transfer is negligible. **4** Initially, the piston is at the average temperature of the two gases.

Properties The gas constants and the constant volume specific heats are $R = 0.2968$ kPa.m^3/kg.K is $c_v = 0.743$ kJ/kg·°C for N_2, and $R = 2.0769$ kPa.m^3/kg.K is $c_v = 3.1156$ kJ/kg·°C for He (Tables A-1 and A-2). The specific heat of copper piston is $c = 0.386$ kJ/kg·°C (Table A-3).

Analysis The mass of each gas in the cylinder is

$$m_{N_2} = \left(\frac{P_1 V_1}{RT_1}\right)_{N_2} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(393\text{ K})} = 4.287\text{ kg}$$

$$m_{He} = \left(\frac{P_1 V_1}{RT_1}\right)_{He} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(2.0769\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(313\text{ K})} = 0.7691\text{ kg}$$



Taking the entire contents of the cylinder as our system, the 1st law relation can be written as

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

$$0 = \Delta U = (\Delta U)_{N_2} + (\Delta U)_{He} + (\Delta U)_{Cu}$$

$$0 = [mc_v(T_2 - T_1)]_{N_2} + [mc_v(T_2 - T_1)]_{He} + [mc(T_2 - T_1)]_{Cu}$$

where

$$T_{1,Cu} = (120 + 40) / 2 = 80°\text{C}$$

Substituting,

$$(4.287\text{ kg})(0.743\text{ kJ/kg}\cdot°\text{C})(T_f - 120)°\text{C} + (0.7691\text{ kg})(3.1156\text{ kJ/kg}\cdot°\text{C})(T_f - 40)°\text{C}$$
$$+ (8\text{ kg})(0.386\text{ kJ/kg}\cdot°\text{C})(T_f - 80)°\text{C} = 0$$

It gives

$$T_f = 83.7°\text{C}$$

where T_f is the final equilibrium temperature in the cylinder.

The answer would be the same if the piston were not free to move since it would effect only pressure, and not the specific heats.