MECH 310 THERMODYNAMICS I
ASSIGNMENT 2

Question 1 (10 points)

Assumptions:
The tank is stationary and thus the kinetic and potential energy changes are zero.
The thermal energy stored in the tank itself is negligible.
We take the contents of the tank as the system.
This is a closed system since no mass enters or leaves.

There are two ways of solving this problem:

Method 1:

The energy balance for this stationary closed system can be approximated by:

$$m*Cp*\Delta T = W_{e,in}$$

$$\text{where } \Delta T = T_{state2} - T_{state1}$$

Note that for this case we assume that Cp remains constant over the temperature range under consideration.

$$W_{e,in} = \mathbf{V}I\Delta t = (50\text{ V})(10\text{ A})(30 \times 60\text{ s})\left(\frac{1\text{ W}}{1\text{ VA}}\right) = 900{,}000\text{ J} = 900\text{ kJ}$$

From Table A.4, Cp of water is given as 4.18 kJ/kg.K

Therefore by substitution into the above equation we calculate $\boldsymbol{T_{state2} = 111.7^{o}C}$

Method 2

The energy balance for this stationary closed system can be expressed as:

$$W_{e,in} = \Delta U = m(u_2 - u_1)$$

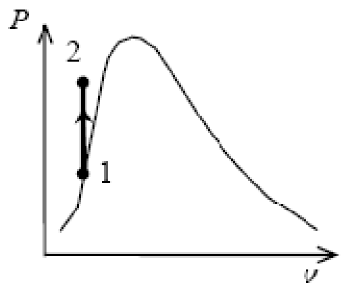
The amount of electrical work added during 30 minutes period is:

$$W_{e,in} = \mathbf{V}I\Delta t = (50\text{ V})(10\text{ A})(30 \times 60\text{ s})\left(\frac{1\text{ W}}{1\text{ VA}}\right) = 900{,}000\text{ J} = 900\text{ kJ}$$

The properties at the initial state are (from Table B.1.1):
At 40^{o}C, u_1= 167.53 kJ/kg and v = 0.000108 m^3/kg

Substituting,

$$W_{e,in} = m(u_2 - u_1) \longrightarrow u_2 = u_1 + \frac{W_{e,in}}{m} = 167.53\text{ kJ/kg} + \frac{900\text{ kJ}}{3\text{ kg}} = 467.53\text{ kJ/kg}$$



We know that the final state will be compressed liquid. Noting that the specific volume is constant during the process, the final temperature is usually determined using an equation of state. However, for our purposes, we cannot find this temperature directly from steam tables at the end of the book. Approximating the final compressed liquid state as saturated liquid at the given internal energy, **the final temperature** is determined (by interpolation between temperatures 110 and 115) from Table B1.1 to be **111.5^{o}C**

The two methods are approximations, which may not be very close to the exact answer (i.e. not within 5% for engineering purposes). The actual answer using the PR equation of state is 118.9^{o}C.

Question 2 (10 points)

Assumptions:
Nitrogen is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of 126.2 K and 3.39 MPa.
The kinetic and potential energy changes are negligible, Δke = Δpe = 0.
Constant specific heats can be used.
We take nitrogen in the cylinder as the system.
This is a closed system since no mass crosses the boundaries of the system.
The properties of nitrogen are R = 0.2968 kJ/kg.K and Cv = 0.745 kJ/kg.K (Table A-5).

The energy balance for this system can be expressed as

$$Q_{\text{in}} - W_{b,\text{out}} = \Delta U = mc_v (T_2 - T_1)$$

Using the boundary work relation for the polytropic process of an ideal gas gives

$$w_{b,\text{out}} = \frac{RT_1}{1-n}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right] = \frac{(0.2968\ \text{kJ/kg}\cdot\text{K})(1200\ \text{K})}{1\text{-}1.35}\left[\left(\frac{120}{2000}\right)^{0.35/1.35} - 1\right] = \mathbf{526.9\ kJ/kg}$$

The temperature at the final state is

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(n\text{-}1)/n} = (1200\ \text{K})\left(\frac{120\ \text{kPa}}{2000\ \text{kPa}}\right)^{0.35/1.35} = 578.6\ \text{K}$$

Substituting into the energy balance equation,

$q_{\text{in}} = W_{b,\text{out}} + cv\ (T_2 - T_1)$ = 526.9 kJ/kg + (0.745 kJ/kg . K)(578.6 −1200)K = **64 kJ/kg**

Question 3 **(10 points)**

In the absence of any work interactions, other than the boundary work, the ΔH and ΔU represent the heat transfer for ideal gases for constant pressure and constant volume processes, respectively. Thus the extra heat that must be supplied to the air maintained at constant pressure is

$$Q_{\text{in, extra}} = \Delta H - \Delta U = mc_p\Delta T - mc_v\Delta T = m(c_p - c_v)\Delta T = mR\Delta T$$

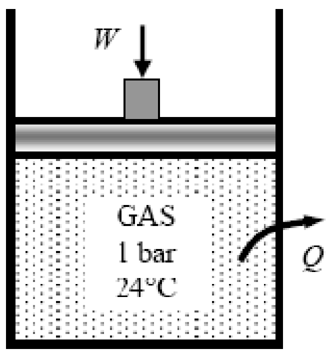
where

$$R = \frac{R_u}{M} = \frac{8.314 \text{ kJ/kmol}\cdot\text{K}}{25 \text{ kg/kmol}} = 0.3326 \text{ kJ/kg}\cdot\text{K}$$

Substituting,

$$Q_{\text{in, extra}} = (12 \text{ kg})(0.3326 \text{ kJ/kg·K})(15 \text{ K}) = \mathbf{59.9 \text{ kJ}}$$

Question 4 **(10 points)**



Assumptions

The kinetic and potential energy changes are negligible, Δke=Δpe=0 .

The friction between the piston and the cylinder is negligible.

We take the ideal gas in the cylinder to be the system.

This is a closed system since no mass crosses the system boundary.

The energy balance for this stationary closed system can be expressed as:

$$W_{\text{b,in}} - Q_{\text{out}} = \Delta U_{\text{ideal gas}} \cong mc_v(T_2 - T_1)_{\text{ideal gas}}) = 0 \quad (\text{since } T_2 = T_1 \text{ and } KE = PE = 0)$$
$$W_{\text{b,in}} = Q_{\text{out}}$$

Thus, the amount of heat transfer is equal to the boundary work input

$$Q_{\text{out}} = W_{\text{b,in}} = \mathbf{0.1 \text{ kJ}}$$

The relation for the isothermal work of an ideal gas may be used to determine the final volume in the cylinder. But we first calculate initial volume

$$V_1 = \frac{\pi D^2}{4} L_1 = \frac{\pi (0.12 \text{ m})^2}{4}(0.2 \text{ m}) = 0.002262 \text{ m}^3$$

Then,

$$W_{b,in} = -P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$0.1\,\text{kJ} = -(100\ \text{kPa})(0.002262\ \text{m}^3)\ln\left(\frac{V_2}{0.002262\ \text{m}^3}\right) \longrightarrow V_2 = 0.001454\ \text{m}^3$$

The final pressure can be determined from ideal gas relation applied for an isothermal process

$$P_1 V_1 = P_2 V_2 \longrightarrow (100\,\text{kPa})(0.002262\,\text{m}^3) = P_2(0.001454\,\text{m}^3) \longrightarrow P_2 = \mathbf{155.6\,kPa}$$

The final position of the piston and the distance that the piston is displaced are

$$V_2 = \frac{\pi D^2}{4} L_2 \longrightarrow 0.001454\,\text{m}^3 = \frac{\pi (0.12\,\text{m})^2}{4} L_2 \longrightarrow L_2 = 0.1285\,\text{m}$$

$$\Delta L = L_1 - L_2 = 0.20 - 0.1285 = 0.07146\,\text{m} = \mathbf{7.1\,cm}$$

Question 5 (10 points)

Assumptions
The kinetic and potential energy changes are negligible, Δke=Δpe=0 .
The gas behaves as an ideal gas.
This is a closed system since no mass crosses the system boundary.

To determine the specific heat capacity, *cp*, start with the energy balance equation:

$$\Delta U = Q - W$$

With $\Delta U = mcv\,\Delta T = m(cp - R)\,\Delta T$

Therefore $cp = \frac{Q-W}{m\Delta T} + R$

Heat transfer out of the system Q = - 20*10*60 = -12,000 J = -12. kJ
Work done on the system W = 12*10*60 = -72,000 J = -72 kJ

Substituting the values into equation, the specific heat capacity of the gas will be given by:

$$\text{cp} = \frac{-12+72}{2*40.3} + \frac{8.314}{28} = 1.041\ \text{kJ/kg}$$