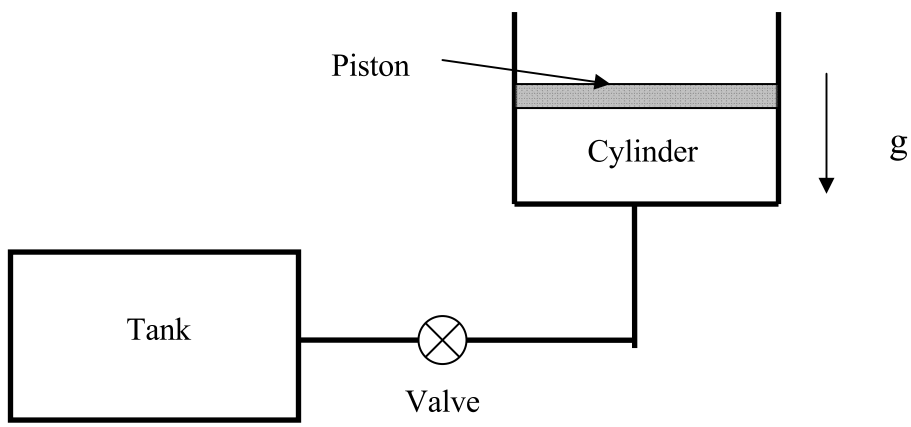
ENSC 461
Assignment #1 (Review)

Problem 1: (the 1st law)

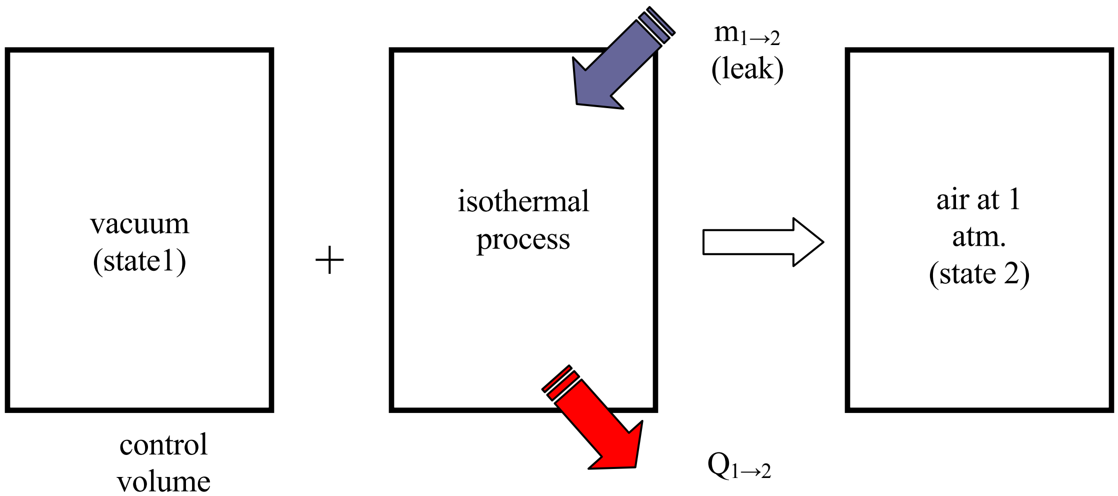
A tank with a volume of 1 m^3 is initially evacuated. Atmospheric air at 101.3 kPa leaks into the tank through a weld imperfection. The process is slow and heat transfer with the surroundings keeps the tank and its contents at the ambient temperature during the process. Calculate the amount and the direction of heat exchanged with the surroundings during the time it takes for the pressure in the tank to reach 1 atmosphere. (Ans. 101.3 kJ)

Problem 2: (entropy)

A tank contains 1 lbm of steam at 400 psia and 700 °F. It is connected through a valve to a vertical cylinder which contains a piston as shown below. Initially the piston rests at the bottom of the cylinder, and its mass is such that a pressure of 180 psia is required to lift it off the bottom of the cylinder. The valve is cracked open so as to allow steam to flow slowly into the cylinder until the pressure is uniform throughout the system. Assuming that no heat is transferred from the steam to the surroundings, and that no heat is exchanged between the two parts of the system, determine the final temperatures in the tank and the cylinder. Also assume that the steam in the tank (not the cylinder) has undergone a frictionless process. (Ans. $T_{tank} \approx 500$ °F, $T_{cylinder} \approx 600$°F)



Problem 1 Solution:



Assumptions:

1- isothermal process
2- process occurs slowly (equilibrium conditions)
3- air is an ideal gas.

The tank is the control volume. We start with the conservation laws.

Mass conservation:

$$\frac{dm_{cv}}{dt} = \overset{0}{m}_{in} - \overset{0}{m}_{out}$$

$$\overset{0}{m}_{out} = 0 \qquad m_1 = 0$$

$$m_2 = m_{in,1\to2}$$

Energy conservation:

$$\frac{dE_{cv}}{dt} = \overset{0}{Q} - \overset{0}{W} + \overset{0}{m}_{in} h_{in} - \overset{0}{m}_{out} h_{out}$$

$$\overset{0}{m}_{out} = 0 \quad \overset{0}{W} = 0$$

thus,

$$U_2 - U_1 = Q_{1\to2} + m_2 h_{in}$$

$$m_2 u_2 - m_1 u_1 = Q_{1\to2} + m_2 h_{in}$$

but $m_1 = 0$

$$Q_{1\to2} = m_2(u_2 - h_{in}) = m_2(u_2 - u_{in} - P_{in}v_{in})$$

from ideal gas; $P_{in}v_{in} = RT_{in}$

$$Q_{1\to2} = \frac{P_2V}{RT_2}\left[(u_2 - u_{in}) - RT_{in}\right] = \frac{P_2V}{RT_2}\left[c_v(T_2 - T_{in}) - RT_{in}\right]$$

Since $T_{in} = T_2$

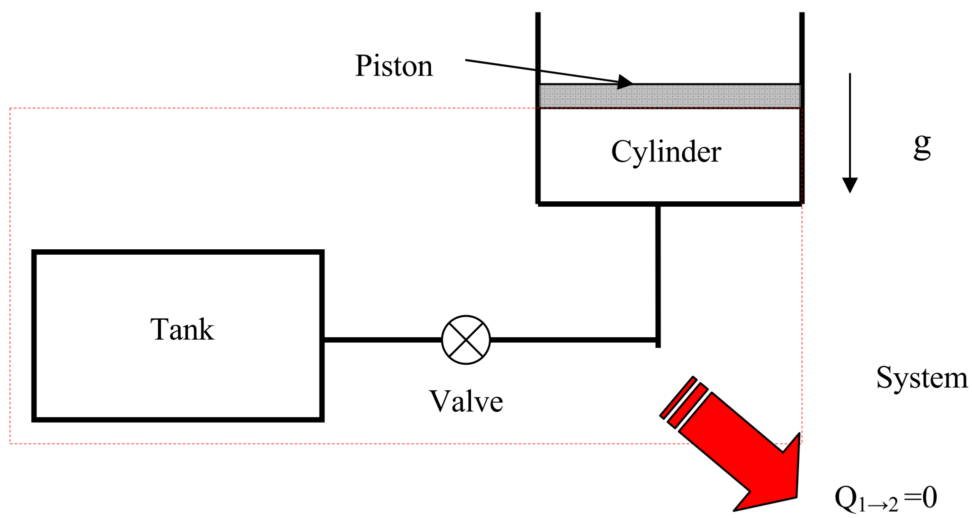
$$Q_{1\to2} = -P_2V = -P_{atm}V = -(101.3kPa)(1m^3) = -101.3kJ$$

Note: the negative sign indicates the heat transfer direction is from the control volume.

Also note that you do not need the final temperature of the tank to solve the problem.

Always solve thermodynamics problems using parameters; substitute the numerical values at the last stage.

Problem 2 Solution:



Assumptions:

1- quasi-equilibrium process
2- no heat transfer from the steam to the surroundings
3- rigid tank (the volume of the tank remain constant during the process)
4- reversible expansion in the tank (isentropic process, $s_2 = s_1$).

For the tank at state 1, we know:

$m_{T,1} = 1$ lbm $\quad T_{T,1} = 700$ F $\quad P_{T,1} = 400$ psia

Using Table A-5E, the saturated temperature of water at 400 psia is 444.62 F; since the steam temperature is higher than the saturated temperature ($T_{T,1} > T_{sat@P1}$), we have superheated steam at state 1. Thus, superheated steam Table A-6E must be used:

$v_{T,1}$ = 1.650 ft^3/lbm $\quad$ $u_{T,1}$ = 1240.4 Btu/lbm $\quad$ $s_{T,1}$ = 1.6398 Btu/lbm.R

Cylinder at state 1: $m_{c,1} = 0$

Tank at state 2:

$$m_{T,2} = \frac{V_T}{v_{T,2}} = \frac{m_{T,1}v_{T,1}}{v_{T,2}} \quad \text{(Eq. 1)}$$

We need specific volume for the steam at state 2 in the tank. Since the process is reversible in the tank $s_{T,2} = s_{T,1}$ = 1.6398 (Btu/lbm. R) and we know the pressure at state 2, $P_{T,2}$ = 180 psia; therefore, state 2 is known. Using Table A-6E;

$T_{T,2} \approx$ 500 °F $\quad$ $v_{T,2}$ = 3.04 ft3/lbm $\quad$ $u_{T,2}$ = 1170 Btu/lbm

Substituting in Eq. (1):

$$m_{T,2} = \frac{m_{T,1}v_{T,1}}{v_{T,2}} = \frac{(1 lbm)(1.650\, ft^3/lbm)}{(3.04\, ft^3/lbm)} = 0.543\, lbm$$

Conservation of mass:

$$m_{T,1} = m_{T,2} + m_{c,2}$$
$$m_{c,2} = 0.457 lbm$$

Conservation of energy:

$$Q_{1\to 2} - W_{1\to 2} = E_2 - E_1$$

$$Q_{1\to 2} = 0$$

$$m_{T,1}u_{T,1} - P_{c,2}m_{c,2}v_{c,2} = m_{T,2}u_{T,2} + m_{c,2}u_{c,2}$$

In the above equation all parameters are known except for $v_{c,2}$ and $u_{c,2}$. Knowing the pressure in the cylinder at state 2, i.e. $P_{c,2}$ and using Table A-6E, an iterative method should be used.

Guess a temperature for $T_{c,2}$; read the parameters from the Table A-6E and substitute them in the above equation. After a few iterations, one will find:

$$T_{c,2} \approx 600\ °F$$