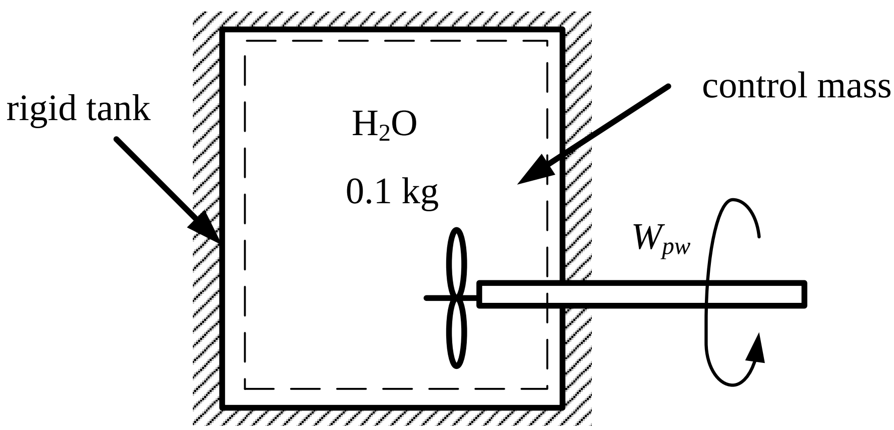
ENSC 388 Week # 4, Tutorial # 3 – Energy Analysis of Closed Systems

Problem 1: One-tenth of a kilogram of water at *3 bars* and *76.3%* quality is contained in a rigid tank which is thermally insulated. A paddle-wheel inside the tank is turned by an external motor until the substance is a saturated vapor. Determine the work necessary to complete the process and the final pressure and temperature of water.

Solution

Step 1: Draw a diagram to represent the system showing control mass/volume of interest.



insulated boundary ($Q = 0$)

Step 2: Write out what you are required to solve for (this is so you don't forget to answer everything the question is asking for)

Find:

a) P_2 - final pressure of the system
b) T_2 - final temperature of the system
c) W - work needed to complete the process

Step 3: Prepare a data table

Data	Value	Unit
m	0.1	$[kg]$
P_1	3	$[bar]$
x_1	0.763	-

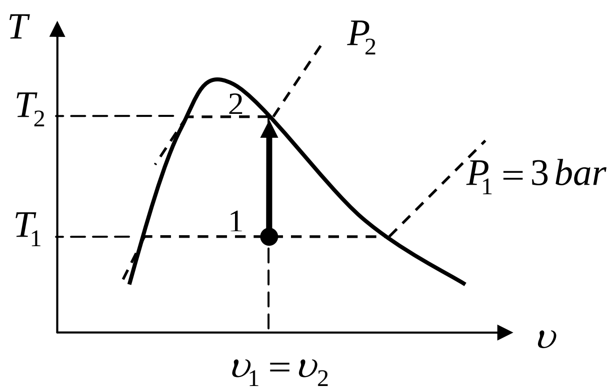
Step 4: State your assumptions (you may have to add to your list of assumptions as you proceed in the problem)

Assumptions:

1) Tank is thermally insulated.
2) Tank is rigid.

Step 5: Calculations

This is a constant volume process in a closed system ($\upsilon = \forall / m = const.$); therefore, the initial specific volume will be equal to the final specific volume. The $T - \upsilon$ diagram for the process can be shown as:



For each state, two independent properties are needed. At initial state (1), the pressure and quality are known.
Since *3 bar = 300 kPa*, from Table **A-5**:

$$P_{sat} = P_1 = 300\ kPa: \begin{cases} T_1 = T_{sat} = 133.52^\circ C \\ \upsilon_{f1} = 0.001073 \left[m^3 / kg \right] \\ \upsilon_{g1} = 0.60582 \left[m^3 / kg \right] \\ u_{f1} = 561.11 \left[kJ / kg \right] \\ u_{fg1} = 1982.1 \left[kJ / kg \right] \end{cases}$$

$$\upsilon_1 = \upsilon_{f1} + x_1(\upsilon_{g1} - \upsilon_{f1}) = \tag{Eq1}$$

$$0.001073 + 0.763(0.60582 - 0.001073) = 0.4625\,[m^3 / kg]$$

$$u_1 = u_{f1} + x_1\, u_{fg1} = \tag{Eq2}$$

$$561.11 + 0.763 \times 1982.1 = 2073.45\,[kJ / kg]$$

At state (2), we have saturated vapor, and since the volume and the mass of the system remain constant, so $\upsilon_1 = \upsilon_2 = \upsilon_{g2}$. From Table **A-5**:

$$\upsilon_{g2} = \upsilon_1 = 0.4625\,[m^3 / kg]: \begin{cases} T_2 = T_{sat} = 143.61^\circ C \\ P_2 = P_{sat} = 400\ [kPa] = 4\,[bar] \\ u_2 = u_{g2} = 2553.1\,[kJ / kg] \end{cases}$$

The energy balance for a closed system can be expressed as:

$$Q - W = \Delta U \tag{Eq3}$$

Since the tank is thermally insulated, $Q = 0$; therefore,

$$W = -\Delta U = -m\left(u_2 - u_1\right) = \tag{Eq4}$$

$$-0.1\left[kg\right]\left(2553.1\left[\frac{kJ}{kg}\right] - 2073.45\left[\frac{kJ}{kg}\right]\right) = -47.965\ kJ$$

The negative sign in the value of the work indicates that the work is done on the system.

Step 6: Concluding Statement

The final temperature and pressure of the system are *143.61°C* and *4 bar*, respectively. Also, *47.965 kJ* work is necessary to do on the system to complete the process.