Next, we consider unsteady state

- Unsteady Process

  - filling closed tanks with a gas or liquid.
  - discharge from closed vessels.

  Basic assumptions are as follows:

  - The control volume remains constant in relation to the coordinate frame.
  - The state of the mass within the control volume may change with time,

$$\boxed{\frac{dm_{cv}}{dt}+\sum \dot{m}_e-\sum \dot{m}_i=0} \quad \text{or} \quad \boxed{(m_2-m_1)_{cv}+\sum m_e-\sum m_i=0} \quad (*)$$

  - The state of the mass crossing each of the areas of flow on the control surface is constant with time, although the mass flow rate may vary with time.

The first law becomes

$$\dot{Q}_{cv}+\sum \dot{m}_i\left(h_i+\frac{V_i^{\,2}}{2}+gz_i\right)=\frac{dE_{cv}}{dt}+\sum \dot{m}_e\left(h_e+\frac{V_e^{\,2}}{2}+gz_e\right)+\dot{W}_{cv}$$

Or

$$Q_{cv}+\sum m_i\left(h_i+\frac{V_i^2}{2}+gz_i\right)=$$

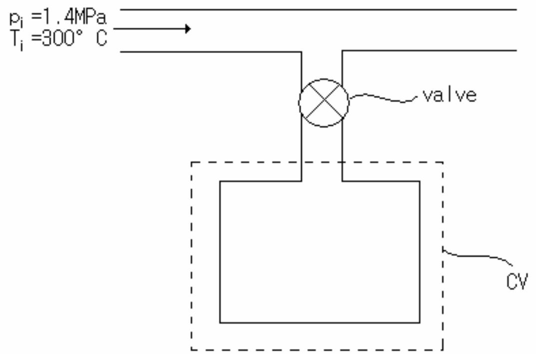
$$\sum m_e\left(h_e+\frac{V_e}{2}+gz_e\right)+\left[m_2\left(u_2+\frac{V_2^2}{2}+gz_2\right)-m_1\left(u_1+\frac{V_1^2}{2}+gz_1\right)\right]_{cv}+W_{cv}$$

---------------(**)

To make any sense to these equations, consider example.

- Example 5-1

  Steam at a pressure of 1.4Mpa, 300°C, is flowing in a pipe. An evacuated tank is connected to this pipe through a valve. The valve is opened, the tank fills with steam until the pressure is 1.4 Mpa, and then the valve is closed. The process takes place adiabatically. Kinetic energies and potential energies are negligible. Determine the final temperature of the steam.



$$\delta Q=0$$

$$\delta KE=\delta PE=0$$

$$m_e=0$$

- Solution to 5-1

  1st law for this unsteady process is

$$\cancel{Q}_{cv}+m_i(h_i)=\cancel{m}_e(h_e)+m_2u_2-\cancel{m}_1u_1+\cancel{W}_{cv}$$

$$m_e=0,\ m_1=0$$

The first law becomes

$$m_ih_i=m_2u_2$$

using continuity (*)

$$(m_2-\cancel{m}_1)+\cancel{m}_e-m_i=0$$

$$m_2=m_1$$

then the first law gives

$$h_i=u_2$$

Solution continued...

That is, the final internal energy of the steam in the tank is equal to the enthalpy of the steam entering the tank.

Look up superheated steam tank at

$p = 1.4MPa,\ T = 300°C$, we find

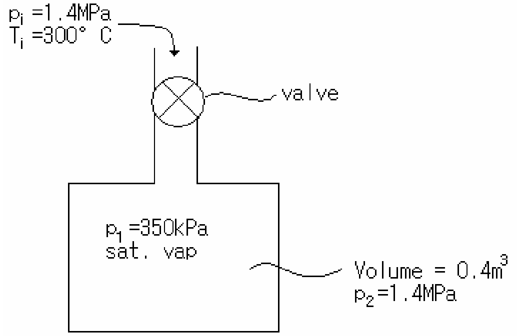
$$h_i = 3040.4\, kJ/kg$$

Then use $h_i = 3040.4 = u_2$ to find state T_2 from the table at $p_2 = 1.4MPa$

$$T_2 \sim 450°C$$

- Example 5-2

  Consider the same tank as in 5-1. Let volume $V = 0.4m^3$, saturated vapor at $p_1 = 350kPa$. The valve is then opened and steam from the line at 1.4 Mpa, 300°C flows into the tank until the pressure is 1.4 Mpa. Calculate the mass of steam that flows into the tank.



$$m_e = 0$$

- Solution to 5-2

  First consider mass balance (*)

$$m_2 - m_1 + \cancel{m_e} - m_i = 0$$

1st Law (**) becomes,

$$m_i h_i = m_2 u_2 - m_1 u_1$$

From saturated steam table at $p_1 = 350kPa,\ v_g = 0.52\, m^3/kg$ of saturated vapor. Thus

$$m_1 = \frac{V_1}{v_g} = \frac{0.4m^3}{0.52\, m^3/kg} = 0.77kg$$

$$u_g = 2548\, kJ/kg = u$$

Solution 5-2 continued...

Again from the superheated steam table, as before at

$$p = 114MPa,\ T = 300°C,\ h_i = 3040.4\, kJ/kg$$

(Trial & Error)

Assume $T_2 = 342°C$

Look up steam (superheated) vapor table at $T_2 = 342°C$ and $p_2 = 1.4MPa$

$$v_2 = 0.1974\, m^3/kg,\ u_2 = 2855.8\, kJ/kg \quad -> \quad m_2 = \frac{V_2}{v_2} = 2.026kg$$

Must use 1st law (**) to check if T_2 guess was good.

$$(m_2 - m_1)h_i = m_2 u_2 + m_1 u_1$$
$$(2.026 - 0.77)3040.4 \approx 2.026(2855.8) - 0.77(2548)$$
$$3818.74 \approx 3823$$

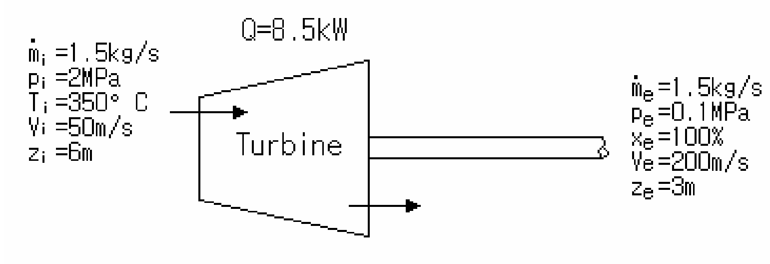
OK guess was good!

Using C (*)

$$m_i = m_2 - m_1$$
$$= 2.026 - 0.77$$
$$= 1.256 kg$$

- Example 5-3 (steady state case)

  The mass rate of flow into a steam turbine is $1.5 kg/s$, and the heat transfer from the turbine is $8.5kW$. The following data are known for the steam entering and leaving the turbine.



Determine the Power ($\dot{W}$) of the turbine.

- Solution to 5-3

  This is a steady state problem.

  Thus c

$$(\cancel{m}_2 - \cancel{m}_1)_{cv} + m_e - m_i = 0$$
$$or \qquad m_e = m_i$$

1st Law (**) becomes

$$\dot{Q}_{cv} + \dot{m}_i (h_i + \frac{V_1^2}{2} + gz_i) = \frac{\cancel{dE_{cv}}}{\cancel{dt}} + \dot{m}_e (h_e + \frac{V_e^2}{2} + gz_e) + \dot{W}_{cv}$$

For h_i, use superheated vapor table at $p_i = 2MPa \ and \ T_i = 350°C$

$\rightarrow \quad h_i = 3137 \, kJ/kg$

In the case of exit, use saturate vapor $p_e = 0.1MPa, \ x_e = 100\%$

$$--> h_e = h_g = 2675.5 \, kJ/kg$$

Upon substitution,

$$\dot{W} = 655.7kW$$

- TA will solve extra practice problems from Chapter 5.
- We will next study the Second Law of Thermodynamics!

- GOOD LUCK, folks!

- Homework Set #4
- due 4/6 (We will have Midterm #1 on the same day)

- 5-3, 5-4, 5-6, 5-9, 5-15, 5-20, 5-26, 5-27, 5-31, 5-33