Chapter 5 First law analysis for an Open System in control volume

- Review of Ch. 4: 1st Law of Thermodynamics in the Closed System

$$\Delta Q \equiv \Delta E + \Delta W$$
$$(\delta Q = dE + \delta W)$$

- Now consider an Open System

CV (control volume) : a volume in space that has interest for a particular study or analysis.

Recall the first law

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

We also note that this may be written as an average rate equation over the time interval ;

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$$\frac{\delta Q}{\delta t} = \frac{E_2 - E_1}{\delta t} + \frac{\delta W}{\delta t}$$

Or $\lim_{\delta t \to 0} \frac{\delta Q}{\delta t} = \dot{Q}$: heat transfer rate

$\lim_{\delta t \to 0} \frac{\delta W}{\delta t} = \dot{W}$: power

$\lim_{\delta t \to 0} \frac{\Delta E}{\delta t} = \frac{dE}{dt}$

$$\dot{Q} = \frac{dE}{dt} + \dot{W}$$
$$= \frac{dU}{dt} + \frac{d(KE)}{dt} + \frac{d(PE)}{dt} + \dot{W}$$

Rate equation form of the First Law

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- Continuous System

The state quantities are expressed in terms of space and time, for example,

$$p = p(x, y, z, t)$$
$$T = T(x, y, z, t)$$

The mass, m and energy E can be expressed using the density, $\rho(x, y, z, t)$

$$m(t) = \int \rho(x, y, z, t)\,dV$$
$$E(t) = \int \rho(x, y, z, t)\,e(x, y, z, t)\,dV$$

If the state of the system does not change with time, $\frac{\partial}{\partial t} \to 0$, it is called "steady state", and we note $\rho(x, y, z)$ and $e(x, y, z)$

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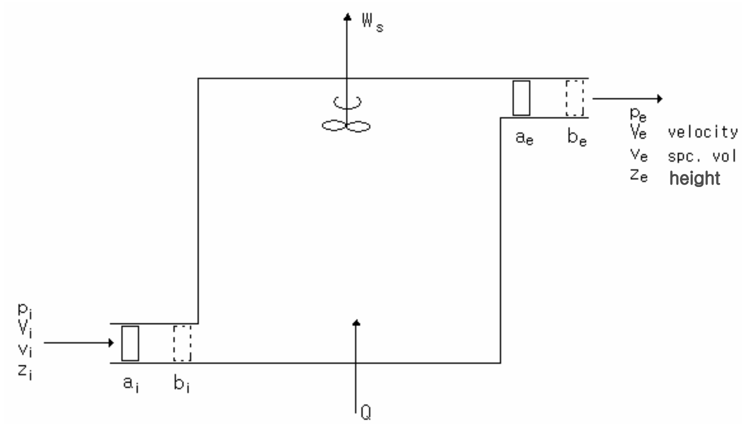
- Consider an Open System (CV)

A typical Open System is depicted below.



Fluid enters through inlet – i (입구) and exits through – e (출구)

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- In order to use the first law for a closed system (ie $\delta Q - \delta W = dE$), we need to modify the system.
- Then, during t and $t+\Delta t$, the total energy considering the inlet and the exit is,

$$E_1 = E_t + \Delta m_i (u_i + \frac{1}{2} V_i^2 + g z_i)$$

$$E_2 = E_{t+\Delta t} + \Delta m_e (u_e + \frac{1}{2} V_e^2 + g z_e)$$

Δt 사이의 열 전달 량: ΔQ

Δt 사이의 일: $\Delta W_s + \Delta W_v$

by Shaft　　by Fluid

$$\Delta W = \Delta W_s - p_i v_i \Delta m_i + p_e v_e \Delta m_e$$

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- Thus the first law as defined for a closed system may be written for an open system (or CV) as follows:

$$\Delta Q - (\Delta W_s - p_i v_i \Delta m_i + p_e v_e \Delta m_e) = \{E_{t+\Delta t} + \Delta m_e (u_e + \tfrac{1}{2} V_e^2 + g z_e)\} - \{E_t + \Delta m_i (u_i + \tfrac{1}{2} V_i^2 + g z_i)\} \quad ---(*)$$

Heat　Work　Total Energy

- If Steady State,

$$\Delta m_i = \Delta m_e = \Delta m$$

$$E_{t+\Delta t} = E_t$$

The state of the mass at each point in the CV does not vary with time, and so does E: $\frac{dm_{cv}}{dt} = 0$; $\frac{dE_{cv}}{dt} = 0$

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- Then the first law for an open system (*) becomes

$$\Delta Q + \Delta m (p_i v_i - p_e v_e) = \Delta W_s + \Delta m (u_e - u_i + \tfrac{1}{2}(V_e^2 - V_i^2) + g(z_e - z_i))$$

using Enthalpy definition (h=u+pv)

$$\Delta Q + \Delta m (h_i + \tfrac{1}{2} V_i^2 + g z_i) = \Delta W_s + \Delta m (h_e + \tfrac{1}{2} V_e^2 + g z_e)$$

In terms of a rate equation,

$$\dot{Q} + \dot{m}(h_i + \tfrac{1}{2} V_i^2 + g z_i) = \dot{W}_s + \dot{m}(h_e + \tfrac{1}{2} V_e^2 + g z_e) \quad -----------(**)$$

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- Thus far, we considered only 1 inlet, 1exit.
- What if there were more than 1?

$$\sum_i \dot{m}_i = \sum_e \dot{m}_e$$

$$\dot{Q} + \sum_i \dot{m}_i (h_i + \tfrac{1}{2} V_i^2 + g z_i) = \dot{W}_s + \sum_e \dot{m}_e (h_e + \tfrac{1}{2} V_e^2 + g z_e)$$

We also note $d\dot{m} = \rho V dA$ then

$$\dot{Q} + \int_{Ai} (h + \tfrac{1}{2} V^2 + g z) \rho V dA = \dot{W}_s + \int_{Ae} (h + \tfrac{1}{2} V^2 + g z) \rho V dA$$

i.e. the cross sectional area of inlet/outlet vary.

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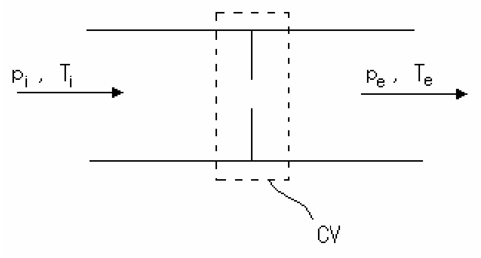
- <u>The Joule–Thomson Coefficient and the Throttling Process</u>

  Let $\mu = (\frac{\partial T}{\partial p})_h$ J–T coefficient.

  Consider a throttling process:

  The flow through a partially opened valve or a restriction in the line. This usually occurs so rapidly and in such a small space that there is neither sufficient force, nor a large enough area for much heat transfer. So we assume such process to the adiabatic



$p_i > p_e$

Reduction in Pressure.

- Thus with steady state assumption, we note,

$$\delta W_s = 0,\ \Delta PE = 0,\ \Delta KE = 0,\ \delta Q = 0$$

Then the 1st Law for the CV becomes

$$h_i = h_e$$

For $\mu > 0,$ $(\Delta p < 0)$

We note, $\Delta T < 0 \quad i.e. T_e < T_i$

For $\mu < 0$ $(\Delta p < 0\ always)$

We note, $\Delta T > 0,\ i.e. T_e > T_i$

For ideal gas, we know h=h(T) only, thus fixing h means T=constant,

$$\left.\frac{\partial T}{\partial P}\right|_{h(T)} = 0 = \mu$$