Lecture 12: Open and closed systems.


\[ \Delta E = \Delta U + \Delta KE + \Delta PE + \Delta FE \]
\[ \Delta E = \left( Q_{in} - Q_{out} \right) + \left( W_{in} - W_{out} \right) + \left( E_{m, in} - E_{m, out} \right) \]

Combining:

\[ \Delta u + \Delta ke + \Delta pe + \Delta P V = \frac{1}{m} (Q - W + E_m) \]

Closed system:

\[ \Delta u + \Delta ke + \Delta pe = Q - W \]

Open system:

\[ \Delta u + \Delta ke + \Delta pe = Q - W + E_m \]

Adiabatic Process:

No heat transfer. Key words: "insulated"; "isolated".

\[ Q_{in} = Q_{out} = Q = 0. \]

1st Law:

"For an adiabatic process between two specified states of a closed system, the work is the same, regardless of the nature of the closed system and the details of the process."

\[ dE = dW \]
Problem 5-15:

System: empty

- 2.5 kg H₂O
- 60°C and 600 kPa

Inside insulated room.

Remove partition:

- \( P_2 = 10 \text{ kPa} \)
- \( v_2 = \) ?
- \( T_2 = \) ?

To find \( T_2 \) and \( v_2 \), we need a 2nd intensive quantity at 2.

\( \Rightarrow \) Something at 1 must be constant during this process.

1st Law: \( \Delta E = 0 \)

\[ \Delta u + \Delta pV + \Delta \text{ke} = 0 = Q - W \]

\( \emptyset \emptyset \emptyset \) stationary, \( \emptyset \emptyset \) no work interaction.

\( \Delta u = Q \)

\( \emptyset \) Adiabatic.

\[ u_2 = u_1 \]

State 1: compressed liquid.
Use (4-4) for liquid at given T.

\[ u_1 = 251.11 \text{ kJ/kg} \]

State 2:
- \( P_2 = 10 \text{ kPa} \)
- \( u_2 = u_1 = 251.11 \text{ kJ/kg} \) \} saturated liquid
- \( v_2 \) vapor mixture.

\[ T_2 = T_{sat} = 45.81°C \]
To get \( v_2 \), we need \( v_2 \rightarrow \) compute the quality.

\[
x = \frac{U - U_f}{U_{fg}} = \frac{251.11 - 191.82}{2246.1} = 0.0264
\]

Find \( v_2 \):

\[
0.0264 = \frac{v_2 - v_f}{v_{fg} - v_f} = \frac{v_2 - 0.001010}{14.67 - 0.001010}
\]

\[
v_2 = 0.388 \, \text{m}^3/\text{kg}_f
\]

The total mass \( m_T \) was given:

\[
V = v_2 \cdot m_T
\]

\[
= 0.388 (2.5)
\]

\[
V_2 = 0.971 \, \text{m}^3
\]
Closed Systems: properties at any location are the same.

Open Systems: properties can vary with location.

Steady-state: All time derivatives are zero. Properties may change in space but not in time.

Homogeneous: All spatial derivatives are zero. Properties may not change in space but may change in time.

**How do we calculate \( E_m \)?**

Take an open system with no heat or work interaction:

\[
m (\Delta u + \Delta ke + \Delta pe + \Delta P\nu) = E_m
\]

\[
E_{in} - E_{out} = m (\Delta u + \Delta ke + \Delta pe)
\]

\[
m (h_1 + ke_1 + pe_1) - m (h_2 + ke_2 + pe_2) = \Delta E.
\]

\[
E_m = m (h + \frac{V^2}{2} + gz)
\]

Now, we can write the energy equation:

\[
\frac{dE}{dt} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + \theta_{in} \dot{m}_{in} - \theta_{out} \dot{m}_{out}
\]

\[
\dot{Q}_{net} = Q \quad W_{net} = W
\]

\[
\frac{dE}{dt} = \dot{Q} - \dot{W} + \Sigma \dot{Q}_{in} \dot{m}_{in} - \Sigma \dot{Q}_{out} \dot{m}_{out}
\]
Comments on Work term: \( W \)
- \( \theta \) already includes work to move fluid in and out of \( C_1 \).
- If the \( C_1 \) does not change shape, there is no boundary work.
- \( W \): must represent shaft work →
  - System does work on surroundings if we rotate a turbine.
  - Surrounds does work on system if a pump impeller is rotating.

Comments on Heat term: \( Q \)
- \( \theta \) already includes heat flowing in and out due to temperature differences in the inlet and outlet flows.
- \( Q \) must be other heat interactions.

\[ \frac{dE}{dt} = \dot{Q} - \dot{W} + \sum_{i}^{n} \left( h_i + \frac{V_i^2}{2} + z_i g \right) - \sum_{j}^{n} \left( h_j + \frac{V_j^2}{2} + z_j g \right) \]

\( \text{all inlets} \quad \text{all outlets} \)

Steady Flow: \( \frac{dE}{dt} = 0 \)

No shaft work: \( \dot{W} = 0 \)
No heat interaction: \( \dot{Q} = 0 \)
No elevation change in ports: \( \Delta z = 0 \)

Translate problem statements into these simplifications.
Conservation of Mass:

Always valid and independent of conservation of $E$.

\[ \frac{dM}{dt} = \sum_{i=1}^{m} \dot{m}_i - \sum_{j=1}^{n} \dot{m}_j \]

inlets \hspace{1cm} outlets.

Problem 5-61: Steady flow nozzle.

\[ A = 50\text{cm}^2 \]
\[ 5\text{MPa} \rightarrow \rightarrow 2\text{MPa} \]
\[ 500^\circ\text{C} \hspace{0.5cm} \rightarrow \hspace{0.5cm} 400^\circ\text{C} \]
\[ V_1 = 80 \frac{\text{m}}{\text{s}} \hspace{0.5cm} Q = 90 \frac{\text{kg}}{\text{s}} = \dot{Q}_{\text{out}} \]

Conservation of mass:

\[ \frac{dM}{dt} = \dot{m}_{\text{in}} - \dot{m}_{\text{out}} \]

0: steady flow device.

\[ \dot{m}_{\text{in}} = \dot{m}_{\text{out}} = \dot{m} \]

Conservation of energy:

\[ \frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}_{\text{in}} \theta_{\text{in}} - \dot{m}_{\text{out}} \theta_{\text{out}} \]

0: steady flow device

0: no shaft work

\[ \theta = -\dot{Q}_{\text{out}} + \dot{m} \theta_{\text{in}} - \dot{m} \theta_{\text{out}} \]

\[ \dot{Q}_{\text{out}} = \dot{m} \left( h_{\text{in}} + \frac{V_{\text{in}}^2}{2} + g z_{\text{in}} \right) - \dot{m} \left( h_{\text{out}} + \frac{V_{\text{out}}^2}{2} + g z_{\text{out}} \right) \]
\[ h_{in} (A-6) = 3433.8 \frac{kJ}{kg} \]
\[ h_{out} (A-6) = 3247.6 \frac{kJ}{kg} \]
\[ v_{in} (A-6) = 0.06857 \frac{m^3}{kg} \]
\[ v_{out} (A-6) = 0.15120 \frac{m^3}{kg} \]

**Conservation of mass:**
\[ \dot{m} = \rho \cdot v \cdot A_1 = \frac{v_1 A_1}{v_i} \]
\[ = \left( \frac{80 \frac{m}{s}}{0.06857 \frac{m^3}{kg}} \right) \left( \frac{50 \text{ cm}^2}{100^2 \text{ cm}^2} \right) \]

\[ \dot{m} = 5.83 \frac{kg}{s} \]

**Conservation of energy:**
\[ \dot{Q}_{out} = \dot{m} \left( h_1 + \frac{v_1^2}{2} + z_1 g \right) - \dot{m} \left( h_2 + \frac{v_2^2}{2} + z_2 g \right) \]

Assume \( z_1 = z_2 \)

\[ -2 \left( \dot{Q}_{out} - \dot{m} \left( h_1 + \frac{v_1^2}{2} \right) \right) = V_2^2 \]

\[ 5.83 \frac{kJ}{kg} \cdot \left( \frac{1 \frac{kJ}{kg}}{1000 \frac{m^2}{s^2}} \right) V_2^2 = -2 \left( 90 \frac{kJ}{s} - 5.83 \frac{kg}{s} \left( 3433.8 \frac{kJ}{kg} \right) + \left( \frac{80 \frac{m^2}{s^2}}{2 \frac{m^2}{s^2}} \right) \left( \frac{1000 \frac{m^2}{s^2}}{1 \frac{kJ}{kg}} \right) + 5.83 \frac{kg}{s} \left( 3247.6 \frac{kJ}{kg} \right) \right) \]

\[ V_2 = 590 \frac{m}{s} \]
Outlet area:

\[ m_1 = m_2 = \frac{V_2 A_2}{U_2} \]

\[ \frac{5.83 \, \text{kg/s}}{590 \, \text{m/s} \, (A_2)} = \frac{0.15120 \, \text{m}^3}{\text{kg}} \]

\[ A_2 = 15 \, \text{cm}^2 \]