IV. First Law of Thermodynamics

D. Applications to steady flow devices
   1. Heat exchangers - example: Clinker cooler for cement kiln

Secondary air
520 °C, 157,000 lbm/h

Clinker
1400 °C, 151 ton/h

Clinker
520 °C, 157,000 lbm/h

Secondary air
20 °C, 157,000 lbm/h

Lesson 12, Geof Silcox, Chemical Engineering, University of Utah
IV. First Law of Thermodynamics

c. Analysis

Solving for $T_{cout}$ gives

$$T_{cout} = \frac{m_c C_c}{m_a C_a} (T_{air} - T_{aout}) + T_{cin}$$

$$T_{cout} = \frac{157,000 \text{ lb} / \text{h}(1040 \text{ J} / \text{kgK})}{302,000 \text{ lb} / \text{h}(1120 \text{ J} / \text{kgK})} (20 \text{ C} - 520 \text{ C}) + 1400 \text{ C} = 1160 \text{ C}$$

Comment: since the heat capacities were evaluated at the average temperatures and the final temperature of the clinker was not known, the value of 1160 C can be used to re-evaluate $C_c$. Iterate until $T_{cout}$ reaches a constant value.

---

IV. First Law of Thermodynamics

2. Nozzles and diffusers (subsonic flows)

a. Nozzles increase velocity at the expense of pressure drop in direction of flow

b. Diffusers increase pressure at the expense of decrease in velocity

$$0 = \frac{\dot{Q}_{CV}}{m} + \left( h + \frac{V^2}{2} \right)_1 - \left( h + \frac{V^2}{2} \right)_2$$

Units: 1 kJ/kg = $10^3$ m²/s²

A common example is the nozzle on a garden or fire hose.
IV. First Law of Thermodynamics

3. Turbines and compressors
   a. In a turbine, a fluid does work on the turbine blades to rotate a shaft.
   b. In a compressor, shaft work from the surroundings does work on the fluid to increase its pressure.
   c. A fan slightly increases pressure in order to move a fluid from one location to another.
   d. Neglect changes in KE and PE. Heat transfer may be negligible as well.

\[
Q_{\text{in}} \triangleq \hat{W}_{\text{in}} + \dot{m}_1 h_1 - \dot{m}_2 h_2
\]

IV. First Law of Thermodynamics

4. Throttling Devices
   a. Used when a decrease in pressure is needed without any work effects.
   b. Accomplished by a partially open valve, a porous plug, or a long capillary tube.
   c. Commonly used in refrigeration where the pressure drop is accompanied by a drop in temperature.
   d. No work. Negligible heat transfer, \(\Delta KE, \Delta PE\).

\[ h_1 = h_2 \]  

(5-41)
IV. First Law of Thermodynamics

e. Example of throttle - refrigeration cycle

Refrigerant 134a is throttled from the saturated liquid state at 700 kPa to a pressure of 120 kPa. What is the drop in temperature?

Recall (5-41), $h_1 = h_2$.

From Table A-12 at 700 kPa, $T_1 = T_{\text{sat}} = 26.69 ^\circ \text{C}$ and $h_1 = h_r = 88.82 \text{ kJ/kg}$.

From Table A-12 at 120 kPa, $h_r = 22.49 \text{ kJ/kg}$ and $h_g = 236.97 \text{ kJ/kg}$. Because $h_1 = h_2 = 88.82 \text{ kJ/kg}$, our final condition is a saturated mixture and $T_2 = T_{\text{sat}} = -22.32 ^\circ \text{C}$
IV. First Law of Thermodynamics

5. Pipe Flow
   a. May have significant heat transfer.
   b. Work term needed if there is a fan or pump in CV.
   c. With liquids $\Delta KE$ usually small. May be important with gases.
   d. $\Delta PE$ can be large for liquid flow, for example, neglecting friction and heat transfer,

\[
W_{in} + \dot{m}_1 g z_1 - \dot{m}_2 g z_2 = 0
\]

E. Unsteady Flow Processes - Example: rapid charging of an evacuated tank
1. Supply line is r-134a at 40 C and 0.14 MPa (absolute). If tank is initially evacuated, find the temperature in the tank when the flow stops (0.14 MPa).
2. Assumptions: (1) no heat transfer to the surroundings during filling, (2) negligible changes in KE and PE.
IV. First Law of Thermodynamics

3. Energy and material balance on contents of tank

\[
\frac{dE_{CV}}{dt} = \dot{Q}_{in} + W_{in} + m_1 \left( h + \frac{V^2}{2} + gz \right)_1 - m_e \left( h + \frac{V^2}{2} + gz \right)_e
\]

\[
\frac{dU_{CV}}{dt} = \dot{m}_i h_i \quad \frac{dm_{CV}}{dt} = \dot{m}_i
\]

a. Integrate energy balance with respect to time

\[
\int_{t_1}^{t_2} \frac{dU_{CV}}{dt} \, dt = \int_{t_1}^{t_2} \dot{m}_i h_i \, dt = h_i \int_{t_1}^{t_2} \frac{dm_{CV}}{dt} \, dt
\]

\[
m_2 u_2 - m_1 u_1 = (m_2 - m_1) h_i
\]

b. Because tank is initially empty, \( m_1 = 0 \) and \( u_2 = h_i \)

c. At 40ºC, 0.14 MPa, from Table A-13, \( h_i = 288.70 \) kJ/kg

d. Interpolate in Table A-13 to find \( T_2 \) to give \( u_2 = h_i \): \( T_2 = 69.6ºC \).
e. Why is the final temperature higher than the inlet temperature, \( T_i = 40ºC \)?