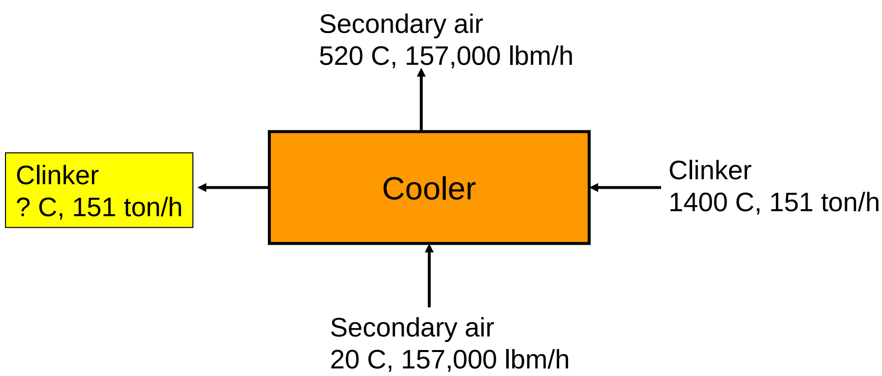
IV. First Law of Thermodynamics

D. Applications to steady flow devices

1. Heat exchangers - example: Clinker cooler for cement kiln



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IV. First Law of Thermodynamics

a. Assumptions

i. changes in kinetic and potential energy are negligible

ii. steady state

iii. constant mass flow rates

iv. negligible heat loss to surroundings

v. negligible nonflow work

vi. Evaluate heat capacities at average temperatures

b. Energy balance over clinker cooler

$$0 = \dot{Q} - \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{V^2}{2} + gz \right)_i - \sum_{out} \dot{m}_e \left(h + \frac{V^2}{2} + gz \right)_e$$

$$\boxed{0 = \sum_{in} \dot{m}_i h_i - \sum_{out} \dot{m}_e h_e}$$

$$\dot{m}_a C_a \left(T_{ain} - T_{aout} \right) = \dot{m}_c C_c \left(T_{cout} - T_{cin} \right)$$

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c. Analysis

Solving for T_{cout} gives

$$T_{cout} = \frac{\dot{m}_a C_a}{\dot{m}_c C_c}(T_{ain} - T_{aout}) + T_{cin}$$

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

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.

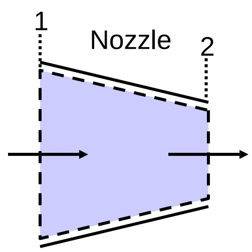
IV. First Law of Thermodynamics

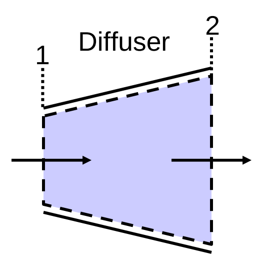
2. Nozzles and diffusers (subsonic flows)
   a. Nozzles increase velocity at the expense of pressure drop in direction of flow
   b. Diffusers increase pressure at the expense of decrease in velocity

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

Units: 1 kJ/kg = 10^3 m^2/s^2

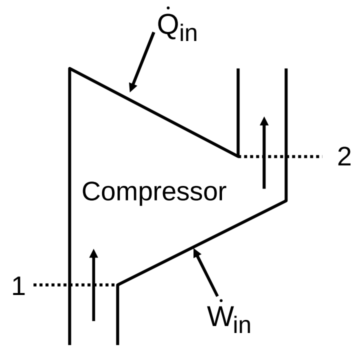
A common example is the nozzle on a garden or fire hose.





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.



$$0 = \dot{W}_{in} + \dot{Q}_{in} + \dot{m}_1 h_1 - \dot{m}_2 h_2$$

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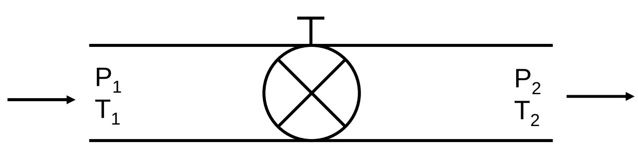
4. Throttling Devices
   a. Used when a decrease in pressure is needed without any work effects.
   b. Accomplished by a partially open valve, a porous plug, or a long capillary tube.
   c. Commonly used in refrigeration where the pressure drop is accompanied by a drop in temperature.
   d. No work.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

$$h_1 = h_2 \qquad (5\text{-}41)$$



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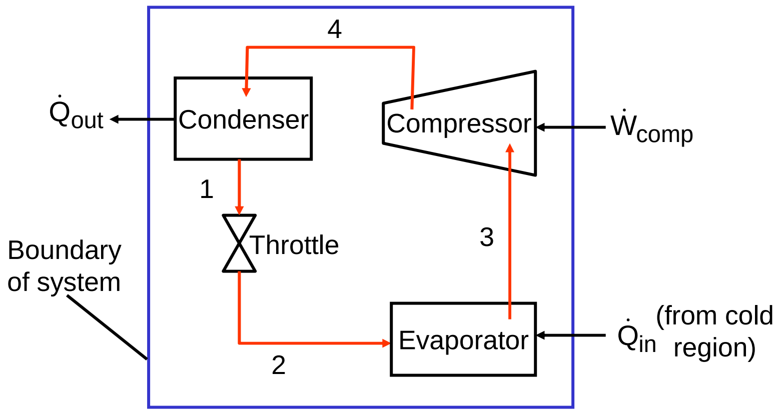
e. Example of throttle - refrigeration cycle

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



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e. Example of throttle - refrigeration cycle

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

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

From Table A-12 at 120 kPa, $h_f = 22.49$ kJ/kg and $h_g = 236.97$ kJ/kg. Because $h_1 = h_2 = 88.82$ kJ/kg, our final condition is a saturated mixture and $T_2 = T_{sat} = -22.32^oC$

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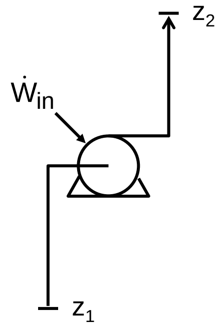
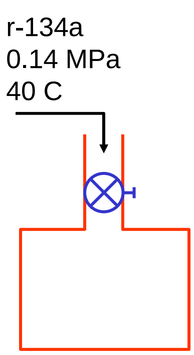
5. Pipe Flow
   a. May have significant heat transfer.
   b. Work term needed if there is a fan or pump in CV.
   c. With liquids ΔKE usually small. May be important with gases.
   d. ΔPE can be large for liquid flow, for example, neglecting friction and heat transfer,

$$\dot{W}_{in} + \dot{m}_1 g z_1 - \dot{m}_2 g z_2 = 0$$



IV. First Law of Thermodynamics

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

$$\frac{dE_{CV}}{dt} = \dot{Q}_{in} + \dot{W}_{in} + \dot{m}_i\left(h + \frac{V^2}{2} + gz\right)_i - \dot{m}_e\left(h + \frac{V^2}{2} + gz\right)_e$$

$$\boxed{\frac{dU_{CV}}{dt} = \dot{m}_i h_i} \qquad \boxed{\frac{dm_{cv}}{dt} = \dot{m}_i}$$

a. Integrate energy balance with respect to time

$$\int_1^2 \frac{dU_{CV}}{dt}dt = \int_1^2 \dot{m}_i h_i dt = h_i \int_1^2 \frac{dm_{cv}}{dt}dt$$

$$m_2u_2 - m_1u_1 = (m_2 - m_1)h_i$$

b. Because tank is initially empty, $m_1 = 0$ and $\boxed{u_2 = h_i}$

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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?