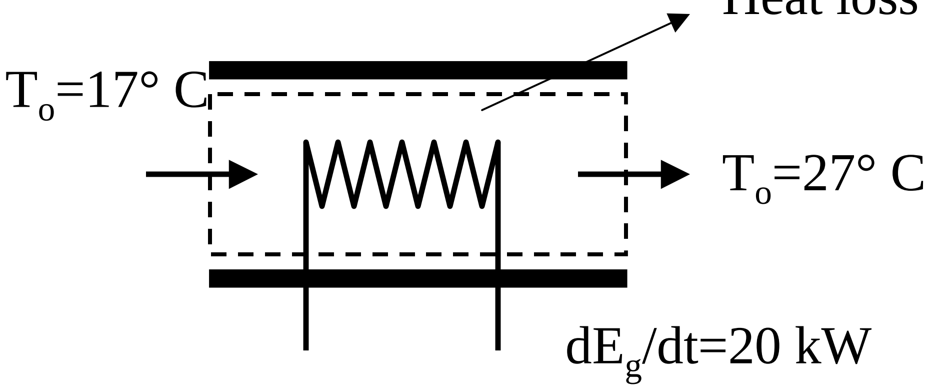
Example: Electric heater is often used in houses to provide heating during winter months. It consists of a simple duct with coiled resistance wires as shown. Consider a 20 kW heating system such that the air enters at 100 kPa and 17° C with a mass flow rate of 2 kg/s. If it is known that the air leaves the duct with an exit temperature of 27° C (same pressure), determine the heat loss from the duct.



Assume: steady state, negligible KE and PE changes, air can be considered as idea gas

$$\frac{dE}{dt} = \frac{\mathrm{dQ}}{\mathrm{dt}} + \frac{dE_g}{dt} + \dot{m}(h + \frac{V^2}{2} + gz)_{in} - \dot{m}(h + \frac{V^2}{2} + gz)_{out} = 0$$

$$\frac{\mathrm{dQ}}{\mathrm{dt}} + \frac{dE_g}{dt} = \dot{m}h_{out} - \dot{m}h_{in}, \quad \frac{\mathrm{dQ}}{\mathrm{dt}} + (20000) = (1.5)(h_{out} - h_{in})$$

From thermo. table A-19(874), $\mathrm{h}_{\mathrm{out}} = C_p T_{out} = 301.5(kJ/kg), h_{in} = 291.5(kJ/kg)$

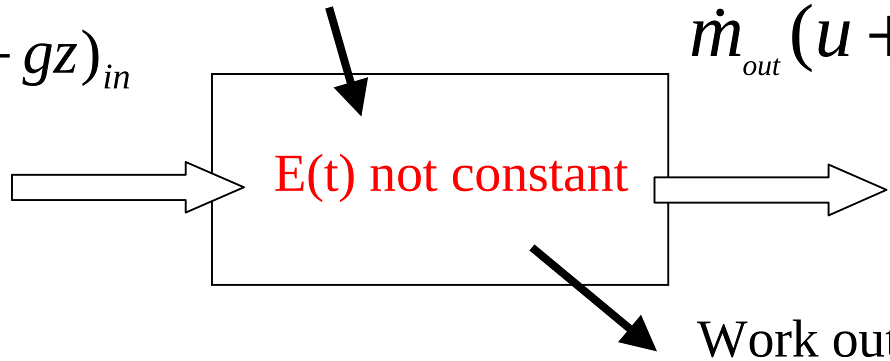
$$\frac{\mathrm{dQ}}{\mathrm{dt}} = (1.8)(301.5 - 291.5)(1,000) - 20,000 = -2,000(W) \quad \rightarrow \text{heat loss}$$

Transient Energy Balance (Unsteady State)

Heat in q=dQ/dt

$$\dot{m}_{in}(u+\frac{p}{\rho}+\frac{V^2}{2}+gz)_{in}$$

$$\dot{m}_{out}(u+\frac{p}{\rho}+\frac{V^2}{2}+gz)_{out}$$



Work out dW/dt

First law of Thermodynamics (Energy Conservation):

$$\frac{\mathrm{dE}}{\mathrm{dt}}=\frac{\mathrm{dE}_g}{\mathrm{dt}}+\dot{E}_{in}-\dot{E}_{out}+(q_{in}-q_{out})-\frac{dW}{dt}, \text{where } \frac{\mathrm{dQ}}{\mathrm{dt}}=(q_{in}-q_{out})$$

$$\dot{E}=\dot{m}(\text{internal energy } + \text{ mechanical energy})=\dot{m}(h+\frac{V^2}{2}+gz)$$

$$\frac{dE}{dt}+\dot{m}(h+\frac{V^2}{2}+gz)_{out}-\dot{m}(h+\frac{V^2}{2}+gz)_{in}=\frac{\mathrm{dQ}}{\mathrm{dt}}-\frac{dW}{dt}\ (\frac{\mathrm{dE}_g}{\mathrm{dt}}=0)$$

This is the same equation as ~~(4.79), pp. 72 in Potter & Somerton~~

(4.19), p. 157 in Cengel's book

Integrate the transient equation in time from 1 to 2:

$$\int [\frac{dE}{dt} + \dot{m}(h + \frac{V^2}{2} + gz)_{out} - \dot{m}(h + \frac{V^2}{2} + gz)_{in}]dt = \int (\frac{\mathrm{dQ}}{\mathrm{dt}} - \frac{dW}{dt})dt$$

$$(E_2 - E_1) + \int [(h + \frac{V^2}{2} + gz)_{out} - (h + \frac{V^2}{2} + gz)_{in}]dm = Q_{12} - W_{12}$$

For uniform flow process: (a) the state of system analyzed is uniform

(b) the fluid flow at the inlet or exit section is uniform and steady

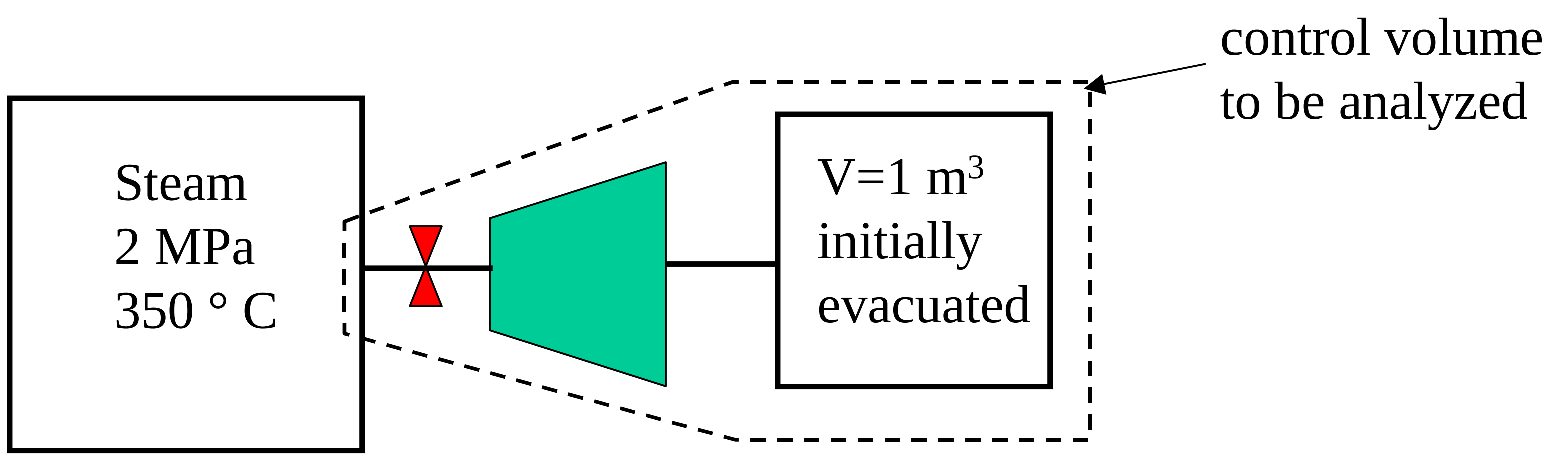
$$(E_2 - E_1) + m_{out}(h + \frac{V^2}{2} + gz)_{out} - m_{in}(h + \frac{V^2}{2} + gz)_{in} = Q_{12} - W_{12}$$

where E (internal energy of system)=mu

Q_{12} : total heat transfer during time from 1 to 2

W_{12} : total work done during time from 1 to 2

Example: Steam at a pressure of 2 MPa and a temperature of 350° C is exiting out from a tank through a valve to drive a turbine as shown. The exhausting steam enters an initially evacuated tank with a volume of 1 m^3. The valve is closed when the second tank is filled with steam at a pressure of 1.4 MPa and a temperature of 500° C. Assume no significant heat transfer and KE and PE changes are also negligible. Determine the amount of work developed by the turbine.



Assumptions: dQ/dt=0 adiabatic process, KE and PE are negligible
Steam properties at the first tank remains constant
The second tank reaches final equilibrium after the filling process ends

Mass conservation

$$\frac{\text{dm}}{\text{dt}} = \dot{m}_{in} - \dot{m}_{out} = \dot{m} \quad \text{since there is no outlet}$$

The unsteady energy balance equation:

$$\frac{dE}{dt} + \dot{m}(h + \frac{V^2}{2} + gz)_{out} - \dot{m}(h + \frac{V^2}{2} + gz)_{in} = \frac{\text{dQ}}{\text{dt}} - \frac{dW}{dt}$$

$$\frac{dE}{dt} - \dot{m}h_{in} = -\frac{dW}{dt}, \text{ adiabatic, no outlet and negligible KE \& PE}$$

$$\text{Integrate over time: } \Delta\text{E=-W+}\int \dot{m}h_{in}dt = -W + h_{in}\int \frac{dm}{dt}dt$$

$$= -W + h_{in}\Delta m$$

Initially the second tank is evacuated

$$\Delta\text{E=E}_\text{f} - E_{initial} = m_f u_f, \ \Delta m = m_f - m_{initial} = m_f$$

$$W = m_f(h_{in} - u_f)$$

0 0

Need to determine properties from table:

The final temperature and pressure of the second tank are 500°C and 1.4 MPa

From table A-6 (p. 853) $\mathrm{v_f} = 0.2521\,\mathrm{m}^3 / kg$

$$m_f = \frac{V}{v_f} = \frac{1}{0.2521} = 3.967(kg)$$

From the same table, $\mathrm{u_f} = 3121.1(kJ / kg)$

Also, the first tank P = 2 MPa, T = 350°C

$\mathrm{h_{in}} = 3137(\mathrm{kJ/kg})$

$\mathrm{W} = \mathrm{m_f}(h_{in} - u_f) = 3.967(3137 - 3121.1) = 63.1(kJ)$