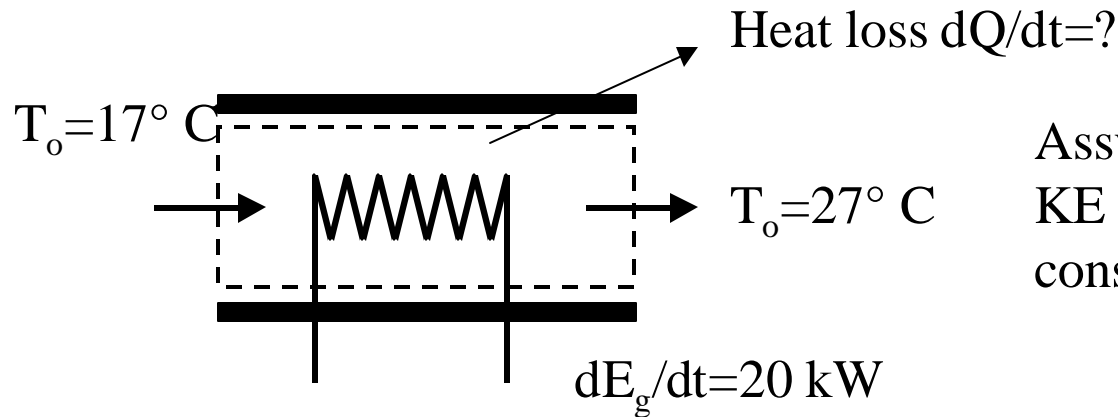


Example: Electric heater is often used in houses to provide heating during winter months. It consists of a simple duct with coiled resistance wires as shown. Consider a 20 kW heating system such that the air enters at 100 kPa and 17° C with a mass flow rate of 1.8 kg/s. If it is known that the air leaves 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

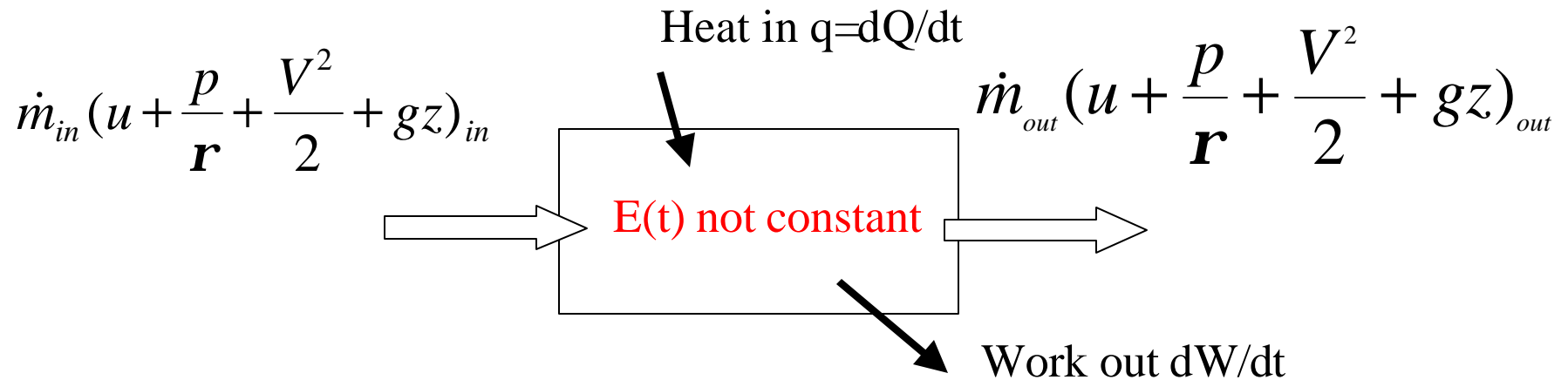
$$\frac{dE}{dt} = \frac{dQ}{dt} + \frac{dE_g}{dt} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{in} - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{out} = 0$$

$$\frac{dQ}{dt} + \frac{dE_g}{dt} = \dot{m}h_{out} - \dot{m}h_{in}, \quad \frac{dQ}{dt} + (20000) = (1.8)(h_{out} - h_{in})$$

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

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

## Transient Energy Balance (Unsteady State)



First law of Thermodynamics (Energy Conservation):

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

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

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

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:

$$\int \left[ \frac{dE}{dt} + \dot{m} \left( h + \frac{V^2}{2} + gz \right)_{out} - \dot{m} \left( h + \frac{V^2}{2} + gz \right)_{in} \right] dt = \int \left( \frac{dQ}{dt} - \frac{dW}{dt} \right) dt$$
$$(E_2 - E_1) + \int \left[ \left( h + \frac{V^2}{2} + gz \right)_{out} - \left( h + \frac{V^2}{2} + gz \right)_{in} \right] dm = Q_{12} - W_{12}$$

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

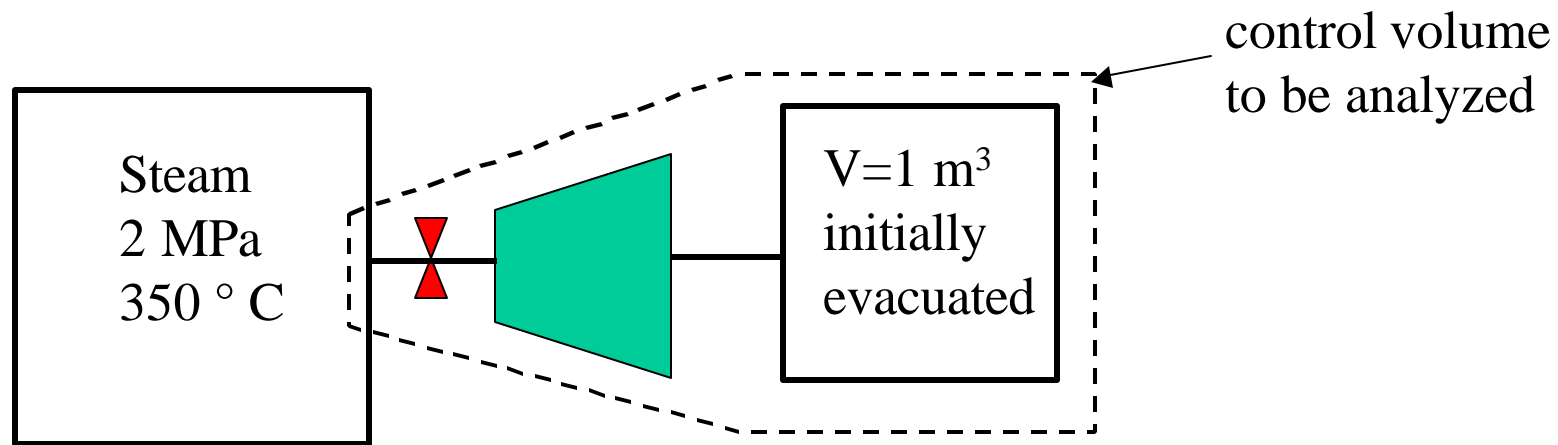
$$(E_2 - E_1) + m_{out} \left( h + \frac{V^2}{2} + gz \right)_{out} - m_{in} \left( h + \frac{V^2}{2} + gz \right)_{in} = Q_{12} - W_{12}$$

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<sup>3</sup>. 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

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

The unsteady energy balance equation:

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

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

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

Initially the second tank is evacuated

$$\Delta E = E_f - E_{initial} = m_f u_f, \quad \Delta m = m_f - m_{initial} = m_f$$

$$W = m_f (h_{in} - u_f) \quad 0$$

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)  $v_f = 0.2521 \text{ m}^3 / \text{kg}$

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

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

Also, the first tank  $P = 2 \text{ MPa}$ ,  $T = 350^\circ\text{C}$

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

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