# CAE 208 Thermal-Fluids Engineering I
# MMAE 320: Thermodynamics

Fall 2022

## November 1, 2022

Mass and Energy Analysis of Control Volumes (iv)

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# ANNOUNCEMENTS

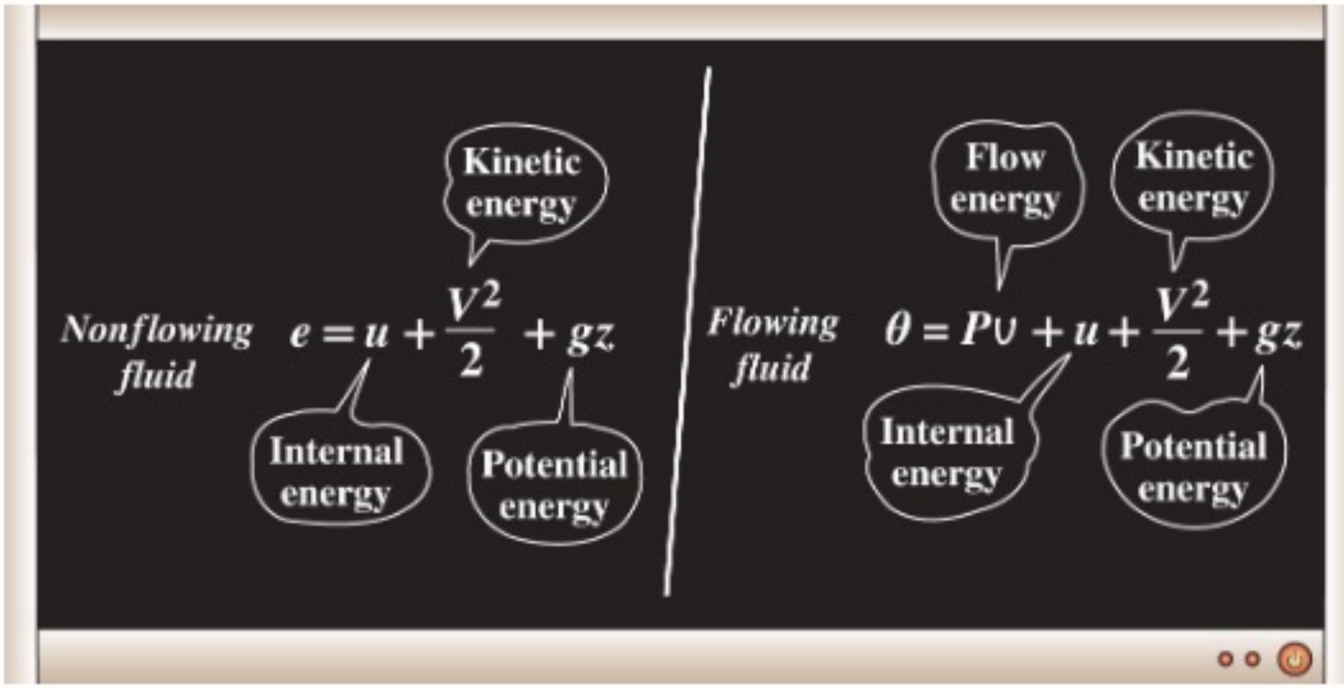
# Announcements

- Assignment 6 due tonight
- Assignment 7 is posted
- Midterm 2 is next Thursday (11/10)

# RECAP

# Recap

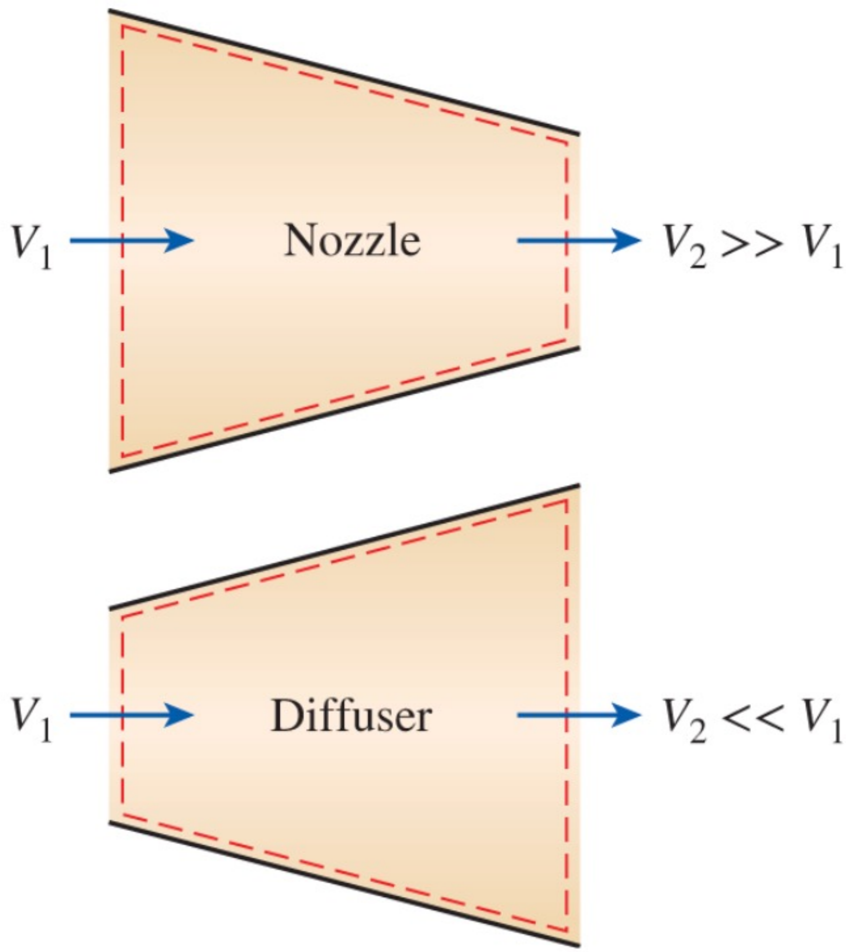
- Total energy of a flowing fluid is:




$$\theta = Pv + e = Pv + (u + ke + pe) = (u + Pv) + ke + pe$$

# Recap

- **Nozzles and Diffusers (steady-flow)**




$$\dot{Q} \cong 0$$

$$\dot{W} = 0\ (most\ times)$$

$$\Delta pe \cong 0$$

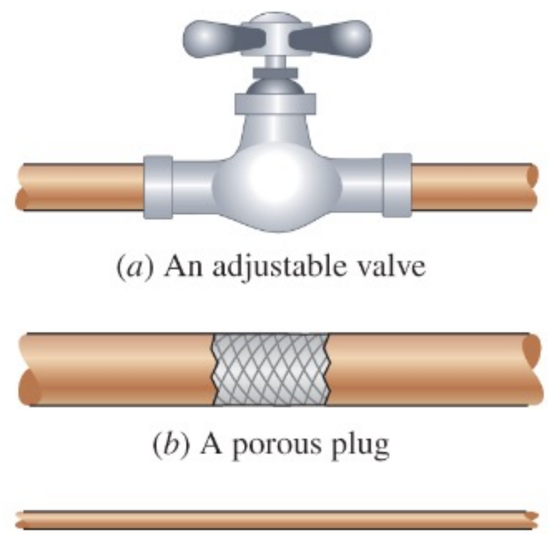
$$\Delta ke \neq 0$$

# Recap

- **Turbines, Compressors, fans, and Pumps (steady-flow)**
  - ❑ Turbine produce power output whereas compressors, pumps, and fans require power input
  - ❑ Heat Transfer is usually negligible ($\dot{Q} \cong 0$)
  - ❑ Potential energy is negligible ($pe \cong 0$)
  - ❑ Kinetic energy is negligible ($ke \cong 0$) - except for fans and turbines but the change in enthalpy is significant compared to the velocity change

# Recap

- **Throttling valves (steady-flow)**
  - ❑ Throttling valves are any kind of flow-restricting devices that cause a significant pressure drop in the fluid (e.g., valves, capillary tubes, porous plugs)
  - ❑ Unlike turbines, they produce a pressure drop without involving any work
  - ❑ The pressure drop in the fluid is often accompanied b a large drop in temperature, and for that reason throttling devices are commonly used in refrigeration and air-conditioning applications



(*a*) An adjustable valve

(*b*) A porous plug

(*c*) A capillary tube

# Recap

- **Throttling valves**
  - They are usually small, the process can be adiabatic ($q \cong 0$)
  - No work is done ($w \cong 0$)
  - $\Delta pe \cong 0$
  - $\Delta ke \cong 0$

$$h_2 \cong h_1$$ *(Isenthalpic device)*

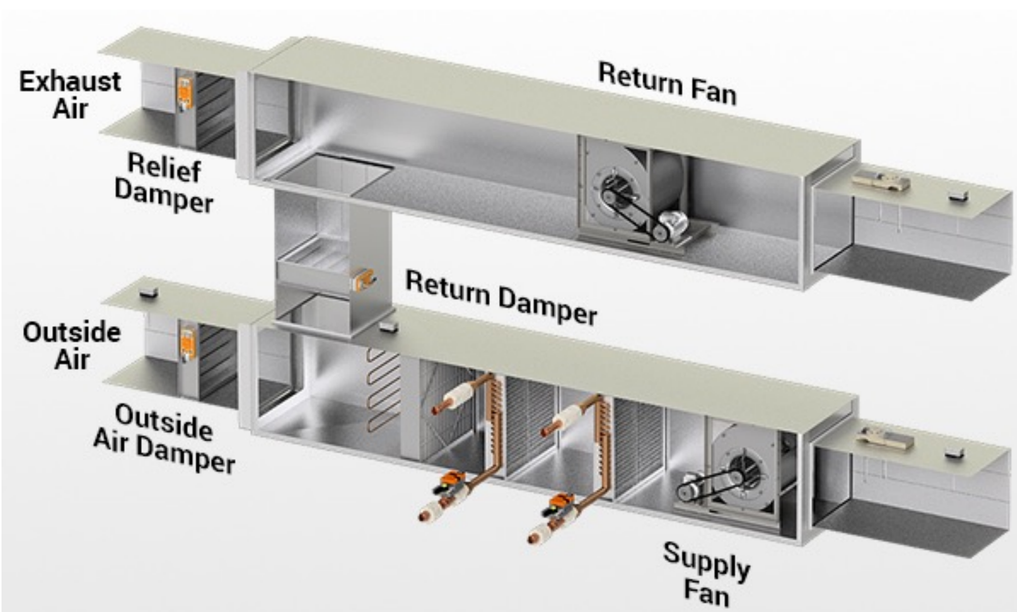
$$u_1 + P_1 v_1 = u_2 + P_2 v_2$$

$$Internal\ energy + Flow\ energy = Constant$$

# SOME STEADY-FLOW ENERGY DEVICES

# Some Steady-Flow Energy Devices

- **Mixing chambers**
  - ❑ In engineering applications, mixing two streams of fluids is not a rate occurrence
  - ❑ They are usually well-insulated ($q \cong 0$)
  - ❑ Do not involve any kind of work ($w \cong 0$)
  - ❑ Kinetic and potential energies negligible ($ke \cong 0$ & $pe \cong 0$)



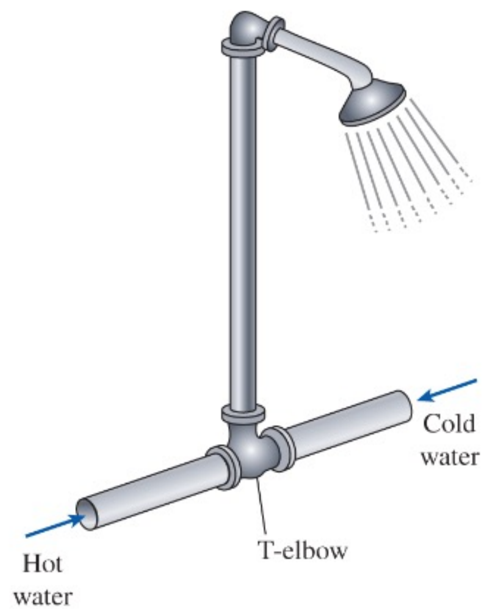






*Photo credit: Belimo*

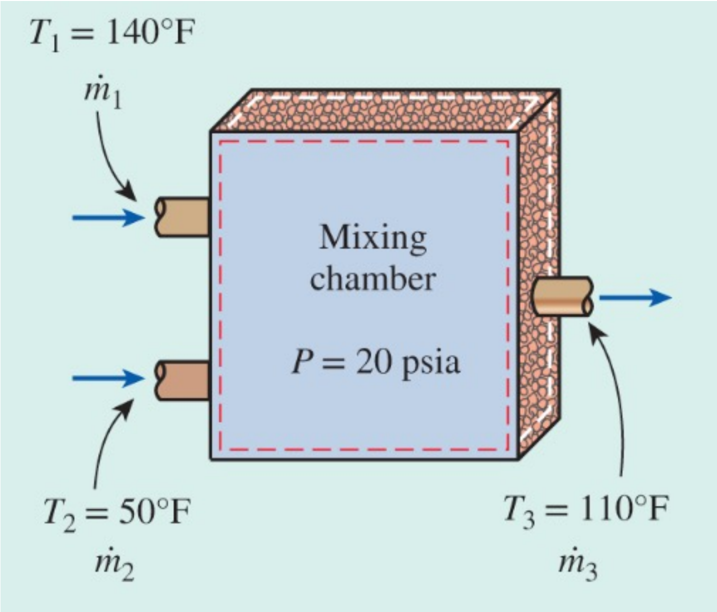
# CLASS ACTIVITY

# Class Activity

- Consider an ordinary shower where hot water at 140 °F is mixed with cold water at 50 °F. If it is desired that a steady steam of warm water at 110 °F be supplied, determine the ratio of the mass flow rates of the hot to cold water. Assume the heat losses from the mixing chamber to be negligible and the mixing to take place at a pressure of 20 psia.

# Class Activity

- Solution (assumptions):
  1. Steady-flow ($\Delta m_{CV} = 0$ and $\Delta \mathrm{E}_{\mathrm{CV}} = 0$)
  2. The kinetic and potential energy changes are zero ($\Delta \mathrm{ke} = \Delta pe = 0$)
  3. Heat losses from the system are negligible ($\dot{Q} \cong 0$)
  4. There is no work interaction involved



# Class Activity

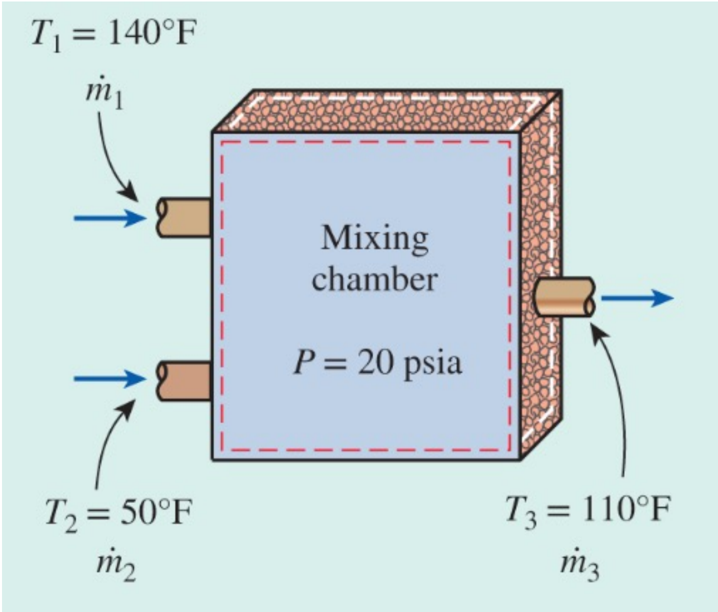
- Solution:

$$\dot{m}_{in} - \dot{m}_{out} = \frac{dm_{system}}{dt} = 0$$

$$\dot{m}_{in} = \dot{m}_{out} \quad \rightarrow \quad \dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$$



# Class Activity

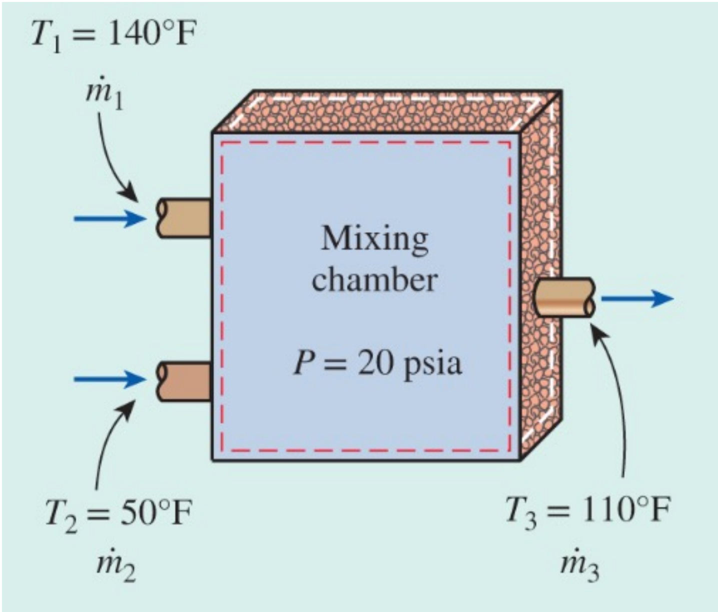
- Solution:

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3$$

$$\left(\frac{\dot{m}_1}{\dot{m}_2}\right) h_1 + \left(\frac{\dot{m}_2}{\dot{m}_2}\right) h_2 = \left(\frac{\dot{m}_1}{\dot{m}_2} + \left(\frac{\dot{m}_2}{\dot{m}_2}\right)\right) h_3$$

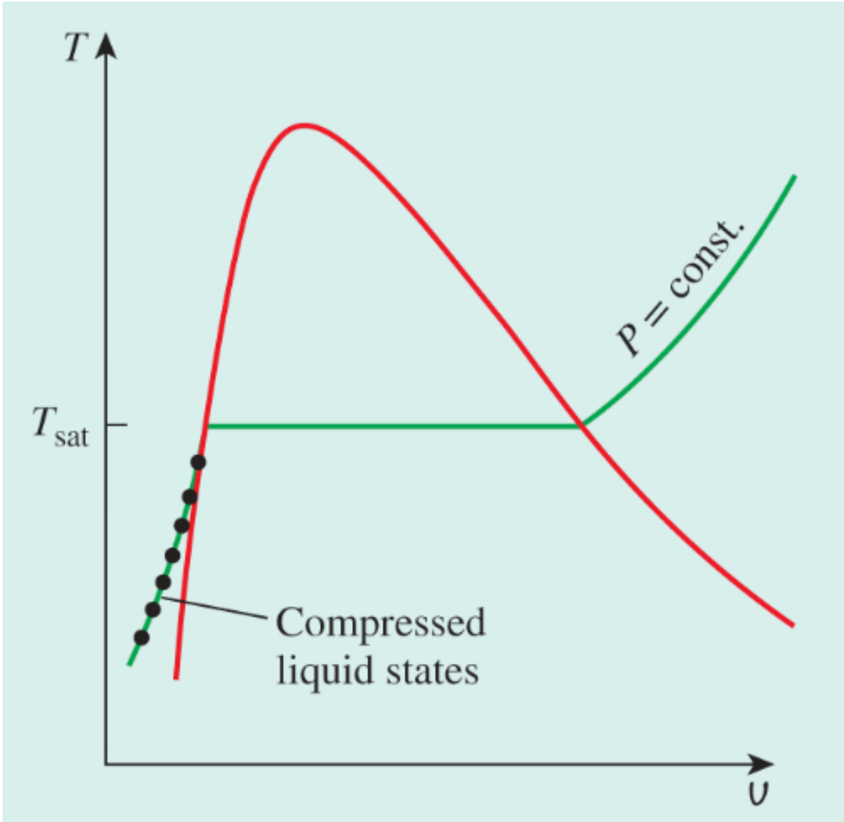
$$y = \frac{\dot{m}_1}{\dot{m}_2}$$

$$y h_1 + h_2 = (y + 1) h_3$$



# Class Activity

- Solution:
  - ❑ The saturation temperature of water at 20 psia is 227.92 °F. Since the temperature of all three steams are below this value ($T<T_{sat}$), the water in all three streams exists as a compressed liquid



# Class Activity

- Solution:

**TABLE A–4E**

Saturated water—Temperature table

| Temp., $T$ °F | Sat. press., $P_{sat}$ psia | Specific volume, ft$^3$/lbm: Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Internal energy, Btu/lbm: Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Enthalpy, Btu/lbm: Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Entropy, Btu/lbm · R: Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32.018 | 0.08871 | 0.01602 | 3299.9 | 0.000 | 1021.0 | 1021.0 | 0.000 | 1075.2 | 1075.2 | 0.00000 | 2.18672 | 2.1867 |
| 35 | 0.09998 | 0.01602 | 2945.7 | 3.004 | 1019.0 | 1022.0 | 3.004 | 1073.5 | 1076.5 | 0.00609 | 2.17011 | 2.1762 |
| 40 | 0.12173 | 0.01602 | 2443.6 | 8.032 | 1015.6 | 1023.7 | 8.032 | 1070.7 | 1078.7 | 0.01620 | 2.14271 | 2.1589 |
| 45 | 0.14756 | 0.01602 | 2035.8 | 13.05 | 1012.2 | 1025.3 | 13.05 | 1067.8 | 1080.9 | 0.02620 | 2.11587 | 2.1421 |
| 50 | 0.17812 | 0.01602 | 1703.1 | 18.07 | 1008.9 | 1026.9 | 18.07 | 1065.0 | 1083.1 | 0.03609 | 2.08956 | 2.1256 |
| 55 | 0.21413 | 0.01603 | 1430.4 | 23.07 | 1005.5 | 1028.6 | 23.07 | 1062.2 | 1085.3 | 0.04586 | 2.06377 | 2.1096 |
| 60 | 0.25638 | 0.01604 | 1206.1 | 28.08 | 1002.1 | 1030.2 | 28.08 | 1059.4 | 1087.4 | 0.05554 | 2.03847 | 2.0940 |
| 65 | 0.30578 | 0.01604 | 1020.8 | 33.08 | 998.76 | 1031.8 | 33.08 | 1056.5 | 1089.6 | 0.06511 | 2.01366 | 2.0788 |
| 70 | 0.36334 | 0.01605 | 867.18 | 38.08 | 995.39 | 1033.5 | 38.08 | 1053.7 | 1091.8 | 0.07459 | 1.98931 | 2.0639 |
| 75 | 0.43016 | 0.01606 | 739.27 | 43.07 | 992.02 | 1035.1 | 43.07 | 1050.9 | 1093.9 | 0.08398 | 1.96541 | 2.0494 |
| 80 | 0.50745 | 0.01607 | 632.41 | 48.06 | 988.65 | 1036.7 | 48.07 | 1048.0 | 1096.1 | 0.09328 | 1.94196 | 2.0352 |
| 85 | 0.59659 | 0.01609 | 542.80 | 53.06 | 985.28 | 1038.3 | 53.06 | 1045.2 | 1098.3 | 0.10248 | 1.91892 | 2.0214 |
| 90 | 0.69904 | 0.01610 | 467.40 | 58.05 | 981.90 | 1040.0 | 58.05 | 1042.4 | 1100.4 | 0.11161 | 1.89630 | 2.0079 |
| 95 | 0.81643 | 0.01612 | 403.74 | 63.04 | 978.52 | 1041.6 | 63.04 | 1039.5 | 1102.6 | 0.12065 | 1.87408 | 1.9947 |
| 100 | 0.95052 | 0.01613 | 349.83 | 68.03 | 975.14 | 1043.2 | 68.03 | 1036.7 | 1104.7 | 0.12961 | 1.85225 | 1.9819 |
| 110 | 1.2767 | 0.01617 | 264.96 | 78.01 | 968.36 | 1046.4 | 78.02 | 1031.0 | 1109.0 | 0.14728 | 1.80970 | 1.9570 |

# Class Activity

- Solution:

$$h_1 \cong h_{f\ @\ 140\,°F} = 107.99\ \frac{Btu}{lbm}$$

$$h_2 \cong h_{f\ @\ 50\,°F} = 18.07\ \frac{Btu}{lbm}$$

$$h_3 \cong h_{f\ @\ 110\,°F} = 78.02\ \frac{Btu}{lbm}$$

# Class Activity

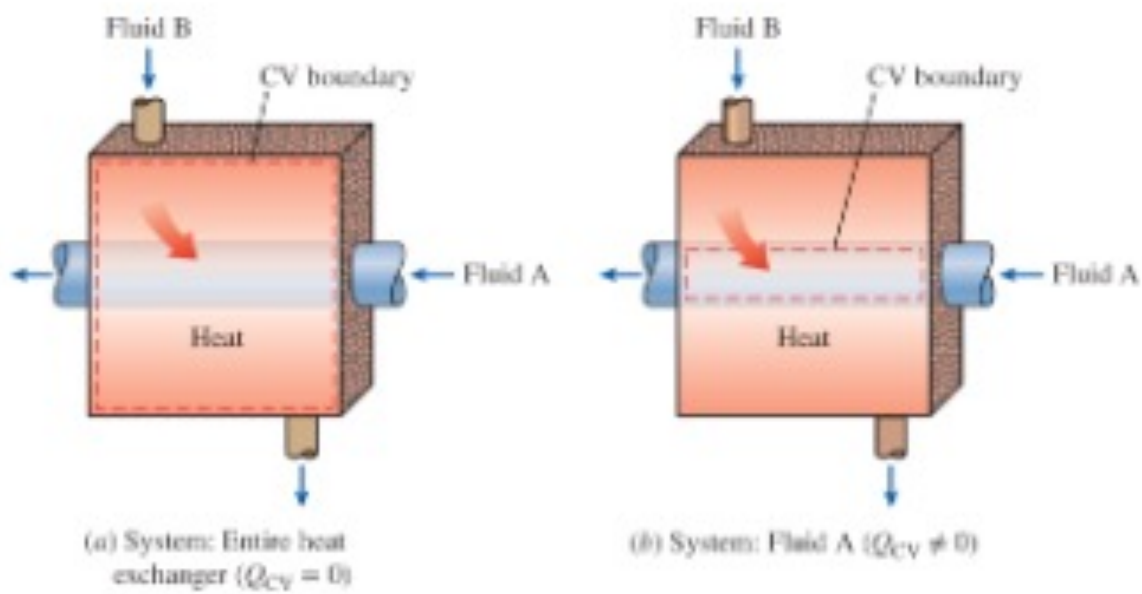
- Solution:
  - ❑ Solving for y and substituting yields:

$$y = \frac{h_3 - h_2}{h_1 - h_3} = \frac{78.02 - 18.07}{107.99 - 78.02} = 2.0$$

$$y = \frac{\dot{m}_1}{\dot{m}_2} = 2 \quad \rightarrow \quad \dot{m}_1 = 2 \times \dot{m}_2$$

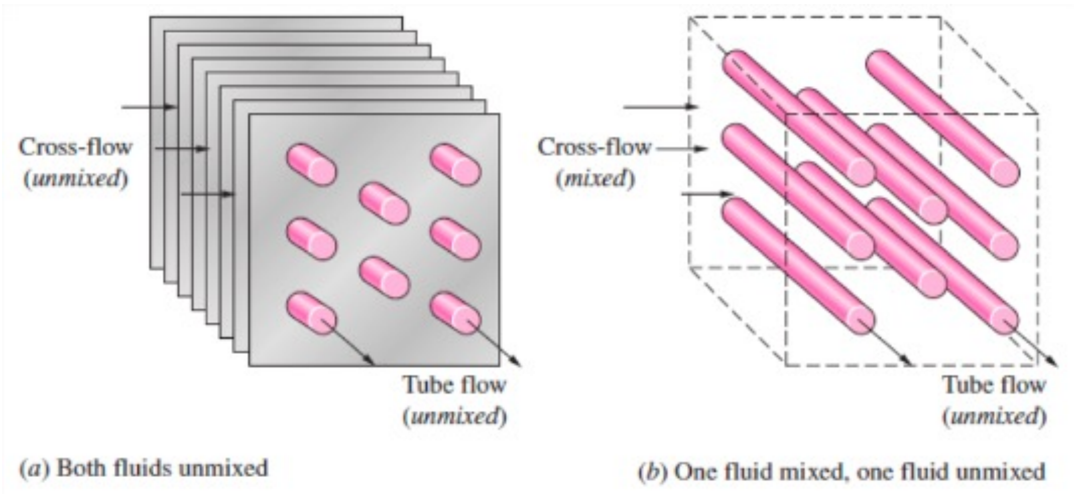
# Some Steady-Flow Energy Devices

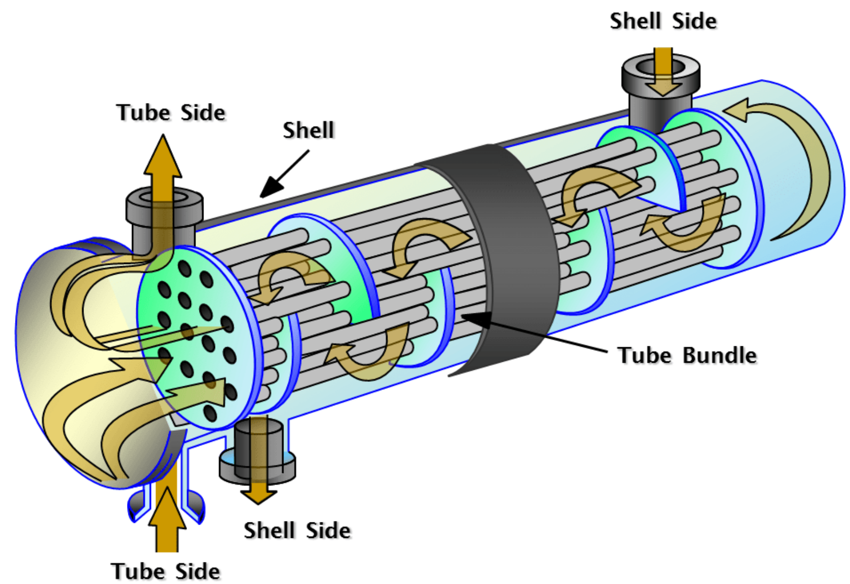
- **Heat Exchangers**
  - Under stead operation, the mass flow rate of each fluid stream flowing through a heat exchanger remains constant
  - Do not involve any kind of work $(w \cong 0)$
  - Kinetic and potential energies negligible $(ke \cong 0 \;\&\; pe \cong 0)$
  - $\dot{Q}$ depends!

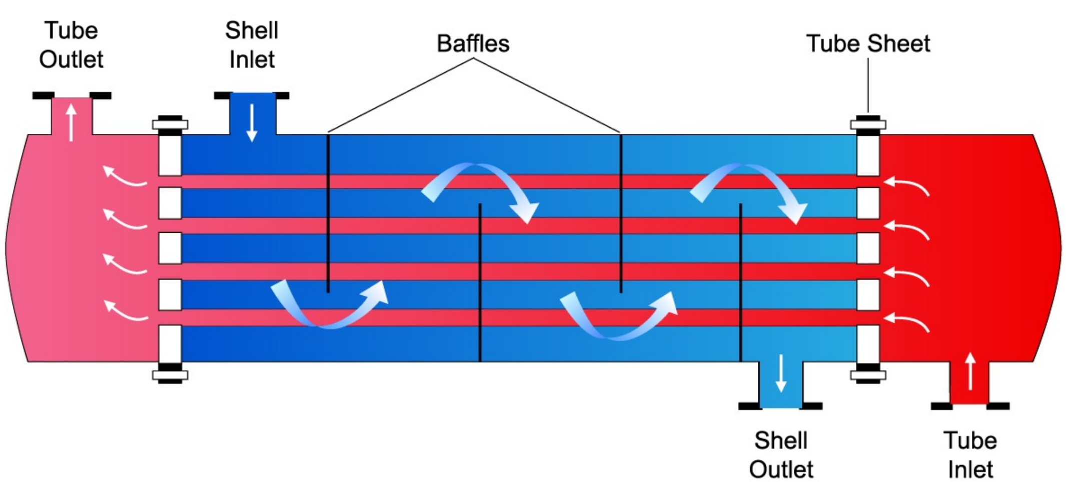


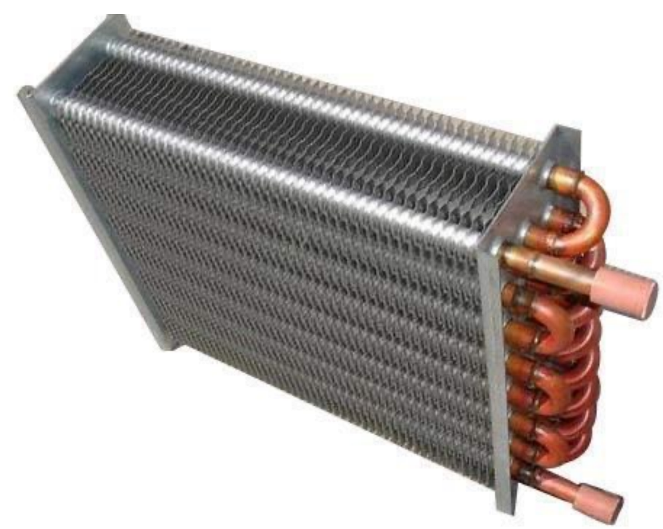
# Some Steady-Flow Energy Devices

- **Heat Exchangers**



# Class Activity

- Refrigerant 134a is to be cooled by water in a condenser. The refrigerant enters the condenser with a mass flow rate of 6 kg/min at 1 MPa and 70 °C (superheated) and leaves at 35 °C (compressed liquid). The cooling water enters at 300 kPa and 15 °C and leaves at 25 °C. Neglecting any pressure drops, determine:

  a) The mass flow rate of the cooling water required
  b) The heat transfer rate from the refrigerant to the water

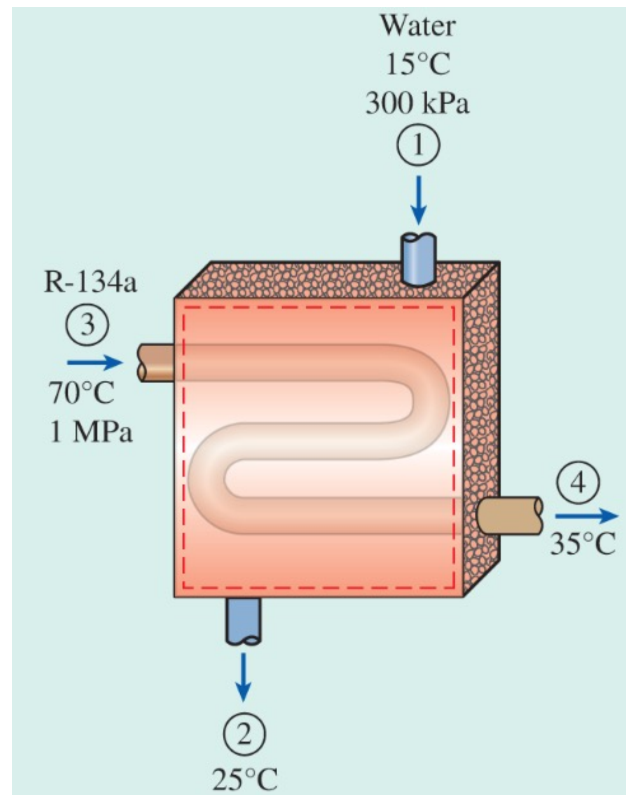
# Class Activity

- Solution (assumptions):
  1. Steady-flow ($\Delta m_{CV} = 0$ and $\Delta \mathrm{E}_{\mathrm{CV}} = 0$)
  2. The kinetic and potential energy changes are zero ($\Delta \mathrm{ke} = \Delta pe = 0$)
  3. Heat losses from the system are negligible ($\dot{Q} \cong 0$)
  4. There is no work interaction involved

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_w$$

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_R$$



# Class Activity

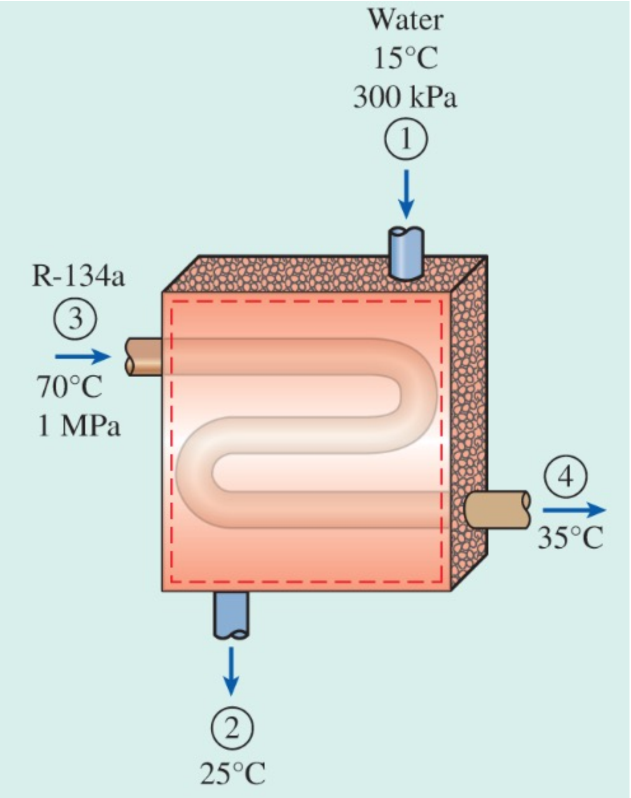
- Solution (a):

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4$$

$$\dot{m}_w (h_1 - h_2) = \dot{m}_R (h_4 - h_3)$$



# Class Activity

- Solution (a):
  - Water exits as a compressed liquid at both the inlet and exit since temperatures at both locations are below the saturation temperature of water at 300 kPa (113.53 °C)

**TABLE A–5**

Saturated water—Pressure table

| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Specific volume, m$^3$/kg: Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Internal energy, kJ/kg: Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Enthalpy, kJ/kg: Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ |
|---|---|---|---|---|---|---|---|---|---|
| 250 | 127.41 | 0.001067 | 0.71873 | 535.08 | 2001.8 | 2536.8 | 535.35 | 2181.2 | 2716.5 |
| 275 | 130.58 | 0.001070 | 0.65732 | 548.57 | 1991.6 | 2540.1 | 548.86 | 2172.0 | 2720.9 |
| 300 | 133.52 | 0.001073 | 0.60582 | 561.11 | 1982.1 | 2543.2 | 561.43 | 2163.5 | 2724.9 |
| 325 | 136.27 | 0.001076 | 0.56199 | 572.84 | 1973.1 | 2545.9 | 573.19 | 2155.4 | 2728.6 |

# Class Activity

- Solution (a):

**TABLE A–4**

Saturated water—Temperature table

| Temp., $T$ °C | Sat. press., $P_{sat}$ kPa | Specific volume, $m^3$/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ |
| 0.01 | 0.6117 | 0.001000 | 206.00 | 0.000 | 2374.9 | 2374.9 | 0.001 | 2500.9 | 2500.9 |
| 5 | 0.8725 | 0.001000 | 147.03 | 21.019 | 2360.8 | 2381.8 | 21.020 | 2489.1 | 2510.1 |
| 10 | 1.2281 | 0.001000 | 106.32 | 42.020 | 2346.6 | 2388.7 | 42.022 | 2477.2 | 2519.2 |
| 15 | 1.7057 | 0.001001 | 77.885 | 62.980 | 2332.5 | 2395.5 | 62.982 | 2465.4 | 2528.3 |
| 20 | 2.3392 | 0.001002 | 57.762 | 83.913 | 2318.4 | 2402.3 | 83.915 | 2453.5 | 2537.4 |
| 25 | 3.1698 | 0.001003 | 43.340 | 104.83 | 2304.3 | 2409.1 | 104.83 | 2441.7 | 2546.5 |
| 30 | 4.2469 | 0.001004 | 32.879 | 125.73 | 2290.2 | 2415.9 | 125.74 | 2429.8 | 2555.6 |

$$h_1 \cong h_{f\,@\,15\,°C} = 62.982\,\frac{kJ}{kg}$$

$$h_2 \cong h_{f\,@\,25\,°C} = 104.83\,\frac{kJ}{kg}$$

# Class Activity

- Solution (a):

$$\left.\begin{aligned} P_3 &= 1\ MPa \\ T_3 &= 70\ °C \end{aligned}\right\} \ (superheated) \rightarrow \ h_3 = 303.87\ \frac{kJ}{kg}$$

**TABLE A–13**

Superheated refrigerant-134a

| $T$ °C | $v$ m$^3$/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|
| | $P = 1.00$ MPa ($T_{sat} = 39.37$°C) | | | |
| Sat. | 0.020319 | 250.71 | 271.04 | 0.9157 |
| 40 | 0.020406 | 251.32 | 271.73 | 0.9180 |
| 50 | 0.021796 | 260.96 | 282.76 | 0.9526 |
| 60 | 0.023068 | 270.33 | 293.40 | 0.9851 |
| 70 | 0.024261 | 279.61 | 303.87 | 1.0160 |
| 80 | 0.025398 | 288.87 | 314.27 | 1.0459 |
| 90 | 0.026492 | 298.17 | 324.66 | 1.0749 |
| 100 | 0.027552 | 307.52 | 335.08 | 1.1032 |
| 110 | 0.028584 | 316.96 | 345.54 | 1.1309 |
| 120 | 0.029592 | 326.49 | 356.08 | 1.1580 |
| 130 | 0.030581 | 336.12 | 366.70 | 1.1847 |
| 140 | 0.031554 | 345.87 | 377.42 | 1.2110 |
| 150 | 0.032512 | 355.73 | 388.24 | 1.2369 |
| 160 | 0.033457 | 365.71 | 399.17 | 1.2624 |
| 170 | 0.034392 | 375.82 | 410.22 | 1.2876 |
| 180 | 0.035317 | 386.06 | 421.38 | 1.3125 |

# Class Activity

- Solution (a):

$$\left.\begin{aligned} P_3 &= 1\ MPa \\ T_3 &= 35\ °C \end{aligned}\right\} (compressed\ liquid) \rightarrow \ h_4 = h_{f\ @\ 35\ °C} = 100.88\ \frac{kJ}{kg}$$

**TABLE A–11**

**Saturated refrigerant-134a—Temperature table**

| | | *Specific volume,* m$^3$/kg | | *Internal energy,* kJ/kg | | | *Enthalpy,* kJ/kg | | |
|---|---|---|---|---|---|---|---|---|---|
| Temp., $T$ °C | Sat. press., $P_{sat}$ kPa | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ |
| 34 | 863.11 | 0.0008535 | 0.023712 | 98.67 | 149.48 | 248.15 | 99.41 | 169.21 | 268.61 |
| 36 | 912.35 | 0.0008595 | 0.022383 | 101.56 | 147.55 | 249.11 | 102.34 | 167.19 | 269.53 |
| 38 | 963.68 | 0.0008657 | 0.021137 | 104.47 | 145.60 | 250.07 | 105.30 | 165.13 | 270.44 |

# Class Activity

- Solution (a):

$$\dot{m}_w(62.982 - 104.83)\left(\frac{kJ}{kg}\right) = \left(6\ \frac{kg}{min}\right)[100.88 - 303.87]\left(\frac{kJ}{kg}\right)$$

$$\dot{m}_w = 29.1\,\frac{kg}{min}$$

# Class Activity

- Solution (b):
  - ❑ We need to choose a control volume for this part: either water or the refrigerant. Here we chose water for no specific reason

$$\dot{E}_{in} - \dot{E}_{out} = \frac{d\dot{E}_{system}}{dt} = 0$$

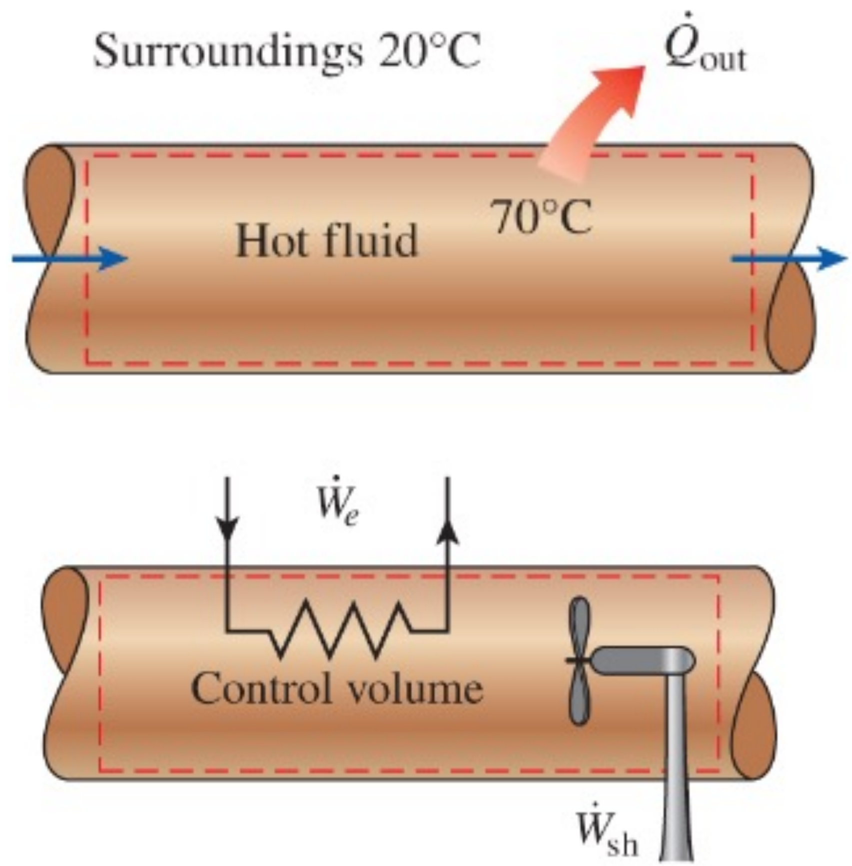
$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{w,in} + \dot{m}_w h_1 = \dot{m}_w h_2$$

$$\dot{Q}_{w,in} = \dot{m}_w (h_2 - h_1) = \left(29.1\,\frac{kg}{min}\right) = \left[(104.83) - (62.982)\,\frac{kJ}{kg}\right] = 1218\,\frac{kJ}{min}$$

# Some Steady-Flow Energy Devices

- **Pipe and Duct Flow**
  - We countered the transport of liquids or gases in pipes and ducts is of great importance in many engineering applications (desired and undesired heat transfer)



# Some Steady-Flow Energy Devices

- **Pipe and Duct Flow**
  - The velocities in pipe and duct flow are relatively low
  - The kinetic energy changes are usually insignificant, especially when the pipe or duct diameter is constant, and the heating effects are negligible (could be important when cross section varies)
  - Potential energy could be significant

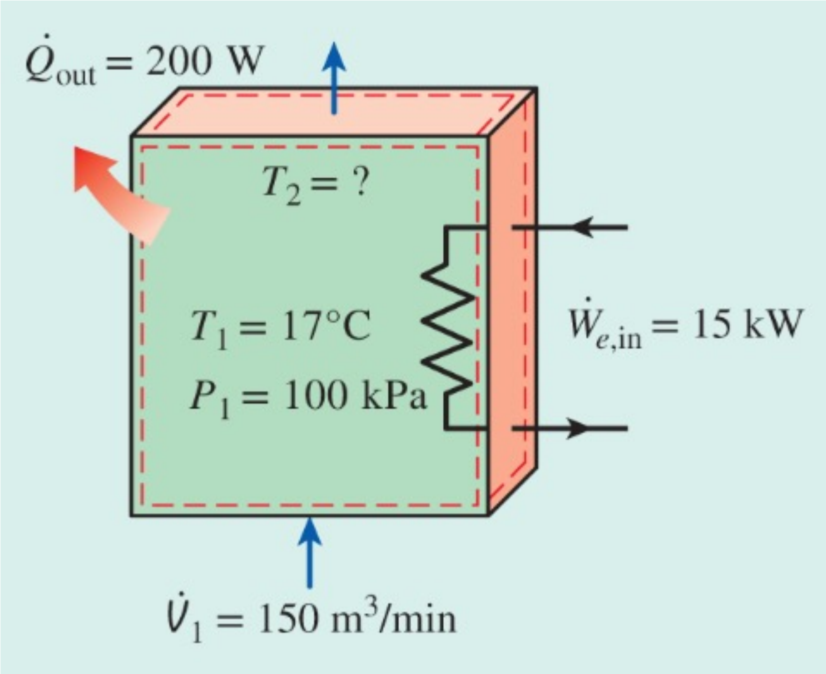
# CLASS ACTIVITY

# Class Activity

- The electric heating systems used in many houses consist of a simple duct with resistance heaters. Air is heated as it flows over resistance wires. Consider a 15.kW electric heating system. Air enters the heating section at 100 kPa and 17 °C with a volume flow rate of 150 $m^3$/min. If heat is lost from the air in the duct to the surroundings at a rate of 200 W, determine the exist temperature of air.

# Class Activity

- Solution (assumptions):
  1. Steady-flow ($\Delta m_{CV} = 0$ and $\Delta \mathrm{E_{CV}} = 0$)
  2. Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values
  3. The kinetic and potential energy changes are zero ($\Delta \mathrm{ke} = \Delta pe = 0$)
  4. Constant specific heats at room temperature can be used for air



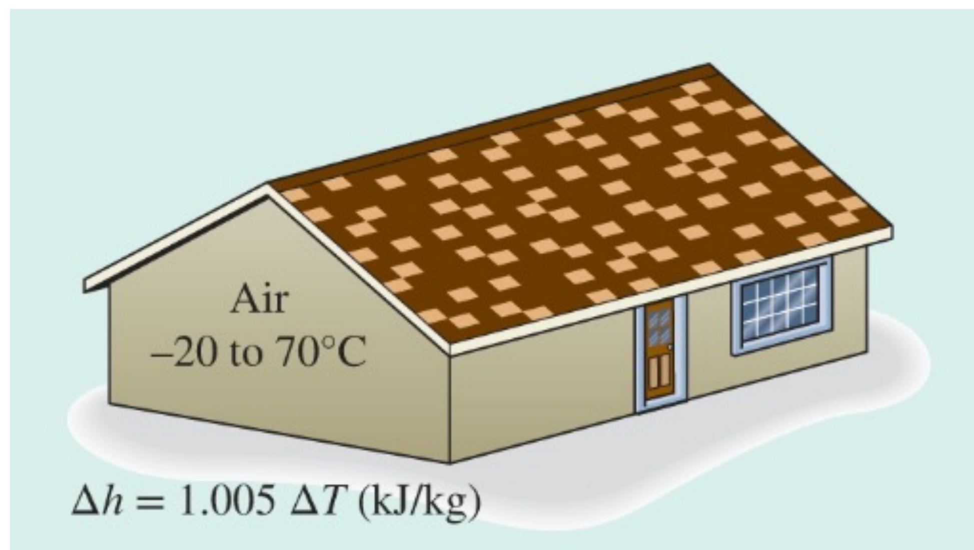
# Class Activity

- Solution:

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{e,in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2$$

$$\dot{W}_{e,in} - \dot{Q}_{out} = \dot{m}c_p(T_2 - T_1)$$



# Class Activity

- Solution:

$$c_p = 1.005 \frac{kJ}{kg - °C}$$ (less than 0.5 percent for air in the range of -20 to 70 °C)

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287 \ \frac{kPa - m^3}{kg - K})(290K)}{100 \ kPa} = 0.832 \frac{m^3}{kg}$$ (Ideal-gas)

$$\dot{m} = \frac{\dot{\forall}_1}{v_1} = \frac{150 \ m^3/min}{0.832 \ m^3/kg}(1 \ min/60 \ s) = 3.0 \ kg/s$$

# Class Activity

- Solution:

$$\left(15\,\frac{kJ}{s}\right) - \left(0.2\,\frac{kJ}{s}\right) = \left(3\,\frac{\text{kg}}{\text{s}}\right)\left(1.005\,\frac{\text{kJ}}{kg - {}^{\circ}C}\right)(T_2 - 17)^{\circ}C$$

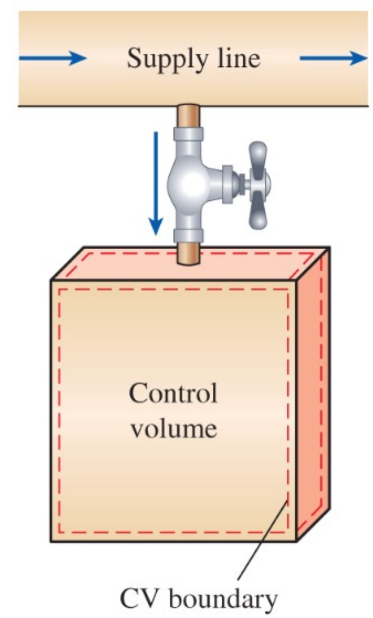
$$T_2 = 21.9\ {}^{\circ}C$$

# ENERGY ANALYSIS O UNSTEADY-FLOW PROCESSES

# Energy Analysis of Unsteady-Flow Processes

- During a steady-flow process, no changes occur within the control volume, so one does not need to be concerned about what is going on within the boundaries

- However, many processes involve change within the control volume with respect to time, which we call them *unsteady-flow* or *transient-flow* processes



# Energy Analysis of Unsteady-Flow Processes

- We deal with changes that occur over some time interval $\Delta t$ instead of with the rate of changes

- At unsteady-flow system in some respects is similar to a closed system, except that the mass within the system boundaries does not remain constant during a process

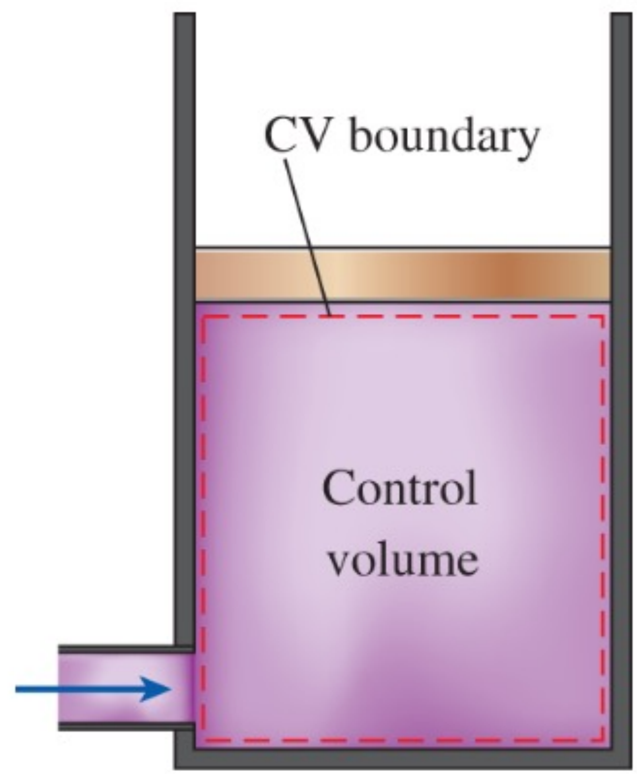
- Steady-flow systems are fixed in space, size, and shape while unsteady-flow systems are not. They are usually stationary that is they are fixed in space, but they may involve moving boundaries and thus boundary work

# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady flow processes:

$$m_{in} - m_{out} = \Delta m_{system}$$

$$\Delta m_{system} = m_{final} - m_{initial}$$



# Energy Analysis of Unsteady-Flow Processes

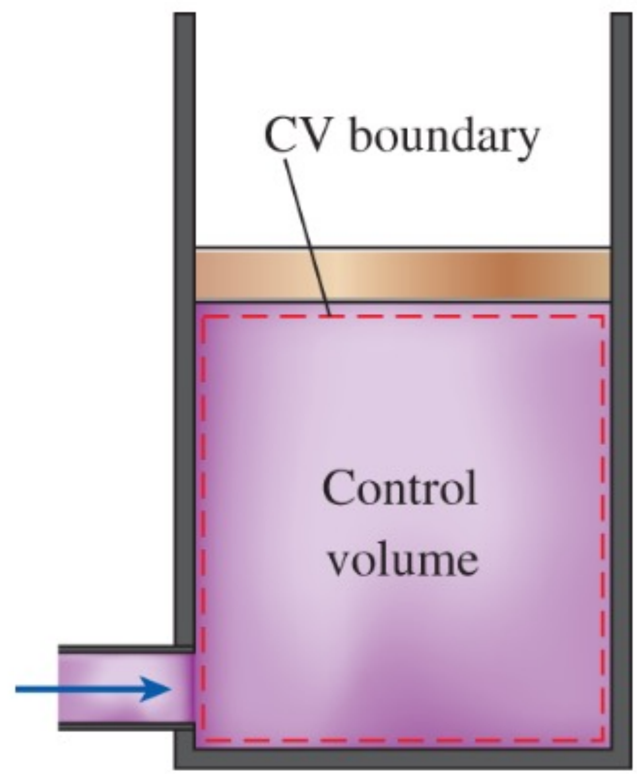
- Let's look at unsteady flow processes and a few cases for mass change:

$$m_i - m_e = (m_2 - m_1)_{CV}$$

# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady energy balance:

$$E_{in} - E_{out} = \Delta E_{system}$$



# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady flow process energy balance
  - ❑ It is difficult to solve
  - ❑ Sometimes we can use uniform-flow process

$$(Q_{in} + W_{in} + \sum_{in} m\theta) - (Q_{out} + W_{out} + \sum_{out} m\theta) = (m_2 e_2 - m_1 e_1)_{system}$$

# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady flow process energy balance
  - A few simplified cases (kinetic and potential energy changes associated with the control volume and fluid streams are negligible):

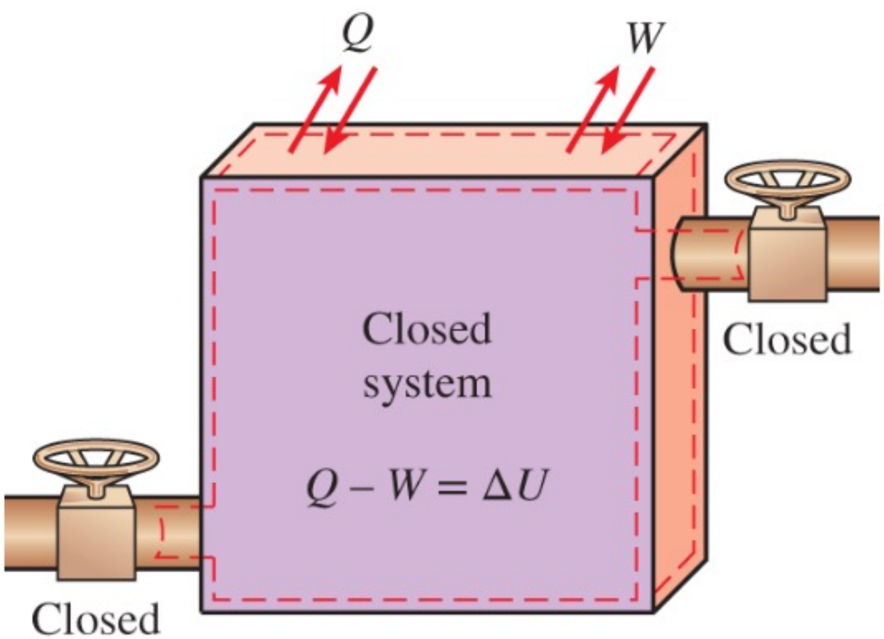
$$Q - W = \sum_{out} mh - \sum_{in} mh + (m_2u_2 - m_1u_1)_{system}$$

$$Q = Q_{net,in} = Q_{in} - Q_{out}$$

$$W = W_{net,in} = W_{in} - W_{out}$$

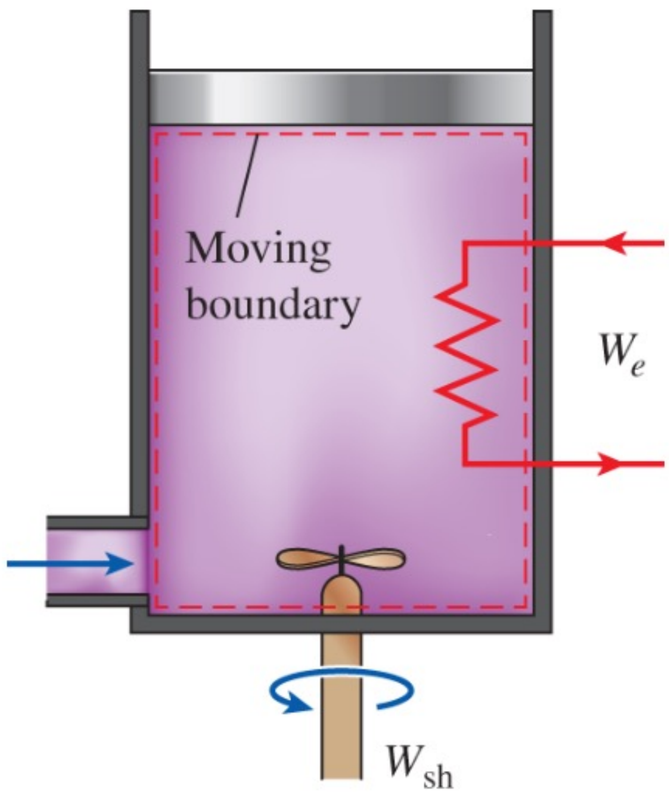
# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady flow process energy balance
  - If no mass enters or leaves the control during a process ($m_i = m_e = 0$ and $m_1 = m_2 = m$), the equation reduces to the energy balance relation for closed systems



# Energy Analysis of Unsteady-Flow Processes

- Let's look at unsteady flow process energy balance
  - ❑ It can also involve work:



# CLASS ACTIVITY

# Class Activity

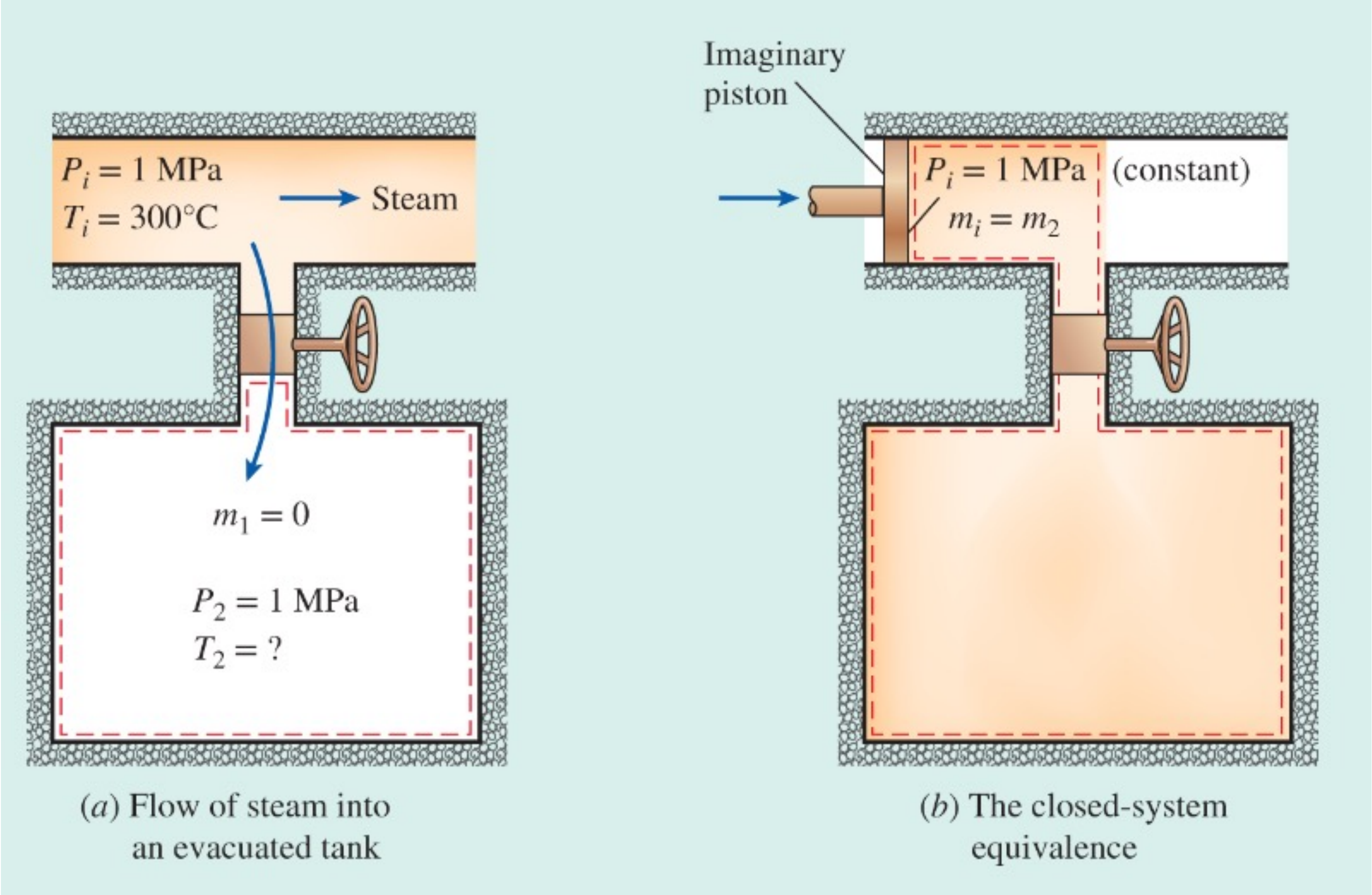
- A rigid, insulated tank that is initially evacuated is connected through a valve to a supply line that carries at 1 MPa and 300 °C. Now the valve is opened, and steam is allowed to flow slowly into the tank until the pressure reaches 1 MPa, at which the valve is closed. Determine the final temperature of the steam in the tank.

# Class Activity

- Solution (assumptions):
  1. This process can be analyzed as a uniform-flow process since the properties of the steam entering the control volume remain constant during the entire process
  2. The kinetic and potential energies of the streams are negligible
  3. The tank is stationary and thus its kinetic and potential energy changes are zero $(\Delta \mathrm{KE} = \Delta PE = 0)$ and $\Delta E_{System} = \Delta U_{System}$
  4. There are no boundary, electrical, or shaft work interactions involved
  5. The tank is well-insulated and this there is no heat transfer

# Class Activity

- Solution:



(*a*) Flow of steam into an evacuated tank

(*b*) The closed-system equivalence

# Class Activity

- Solution (mass balance):

$$m_{in} - m_{out} = \Delta m_{system} = m_2 - m_1$$

$$m_i = m_2$$

# Class Activity

- Solution (energy balance):

$$E_{in} - E_{out} = \Delta E_{system}$$

$$m_i h_i = m_2 u_2$$

$$h_i = u_2$$

# Class Activity

- Solution (finding states):

$$\left.\begin{aligned} P_i &= 1\ MPa \\ T_i &= 300\ °C \end{aligned}\right\} \rightarrow\ h_i = 3051.6\,\frac{kJ}{kg}$$

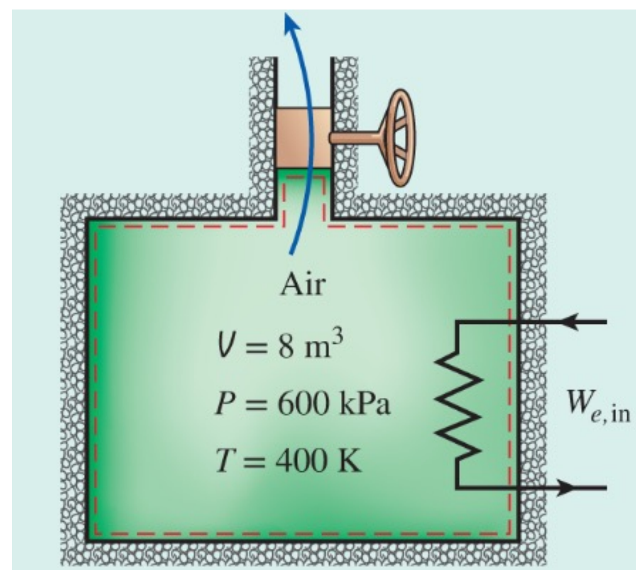
$$h_i = 3051.6\,\frac{kJ}{kg} = u_2$$

$$\left.\begin{aligned} P_2 &= 1\ MPa \\ h_2 &= 3051.6\,\frac{kJ}{kg} \end{aligned}\right\} \rightarrow T_2 = 456.1\ °C$$

# CLASS ACTIVITY

# Class Activity

- An insulated 8 m$^3$ rigid tank contains air at 600 kPa and 400 K. A valve is connected to the tank is now opened, and air is allowed to escape until the pressure inside drops to 200 kPa. The air temperature during the process is maintained constant by an electric resistance heater placed in the tank. Determine the electrical energy supplied to air during this process.



# Class Activity

- Solution (assumptions):
  1. This process can be analyzed as a uniform-flow process since the properties of the steam entering the control volume remain constant during the entire process
  2. The kinetic and potential energies of the streams are negligible
  3. The tank is insulated, so heat transfer can be negligible
  4. Air is an ideal gas

# Class Activity

- Solution (mass balance):

$$m_{in} - m_{out} = \Delta m_{system} = m_2 - m_1$$

$$m_e = m_1 - m_2$$

# Class Activity

- Solution (energy balance):

$$E_{in} - E_{out} = \Delta E_{system}$$

$$W_{e,in} - m_e h_e = m_2 u_2 - m_1 u_1$$

# Class Activity

- Solution (calculating masses):

$$R = 0.287 \frac{kPa.m^3}{kg-K}$$ (Table A-1)

$$m_1 = \frac{P_1 v_1}{RT_1} = \frac{(600\ kPa)(8\ m^3)}{(0.287\ \frac{kPa - m^3}{kg - K})(400\ K)} = 41.81\ kg$$

$$m_2 = \frac{P_1 v_1}{RT_1} = \frac{(200\ kPa)(8\ m^3)}{(0.287\ \frac{kPa - m^3}{kg - K})(400\ K)} = 13.94\ kg$$

$$m_e = m_1 - m_2 = 41.81 - 13.94 = 27.87\ kg$$

# Class Activity

- Solution (calculating masses):

$$at\ 400\ K\ (Table\ A-21): \begin{cases} h_e = 400.98\,\dfrac{kJ}{kg} \\ u_1 = u_2 = 286.16\,\dfrac{kJ}{kg} \end{cases}$$

$$W_{e,in} = m_e h_e + m_2 u_2 - m_1 u_1$$

$$W_{e,in} = (27.87\ kg)\left(400.98\,\frac{kJ}{kg}\right) + (13.94\ kg)\left(286.16\,\frac{kJ}{kg}\right) - (41.81\ kg)\left(286.16\,\frac{kJ}{kg}\right)$$
$$= 3200\ kJ = 0.889\ kWh$$