Ain Shams University
Faculty of Engineering
Mechanical Power Dept.

2014/2015
ENGR 360/MEP 112
Thermodynamics

Sheet (5)
Model Answer

Problem (1):

a- Mass flow rate is the amount of mass flowing through a cross-section per unit time whereas the volume flow rate is the amount of volume flowing through a cross-section per unit time.

b- No, a flow with the same volume flow rate at the inlet and the exit is not necessarily steady (unless the density is constant). To be steady, the mass flow rate through the device must remain constant.

c- Energy can be transferred to or from a control volume as heat, various forms of work, and by mass.

d- A steady-flow system involves no changes with time anywhere within the system or at the system boundaries.

e- No.

f- It is mostly converted to internal energy as shown by a rise in the fluid temperature.

g- The kinetic energy of a fluid increases at the expense of the internal energy as evidenced by a decrease in the fluid temperature.

h- Yes.

i- The volume flow rate at the compressor inlet will be greater than that at the compressor exit.

j- Yes. Because energy (in the form of shaft work) is being added to the air.

k- No.

l- The temperature of a fluid can increase, decrease, or remain the same during a throttling process. Therefore, this claim is valid since no thermodynamic laws are violated.

m- Yes, if the mixing chamber is losing heat to the surrounding medium.

n- Under the conditions of no heat and work interactions between the heat exchanger and the surrounding medium.

Problem (2):

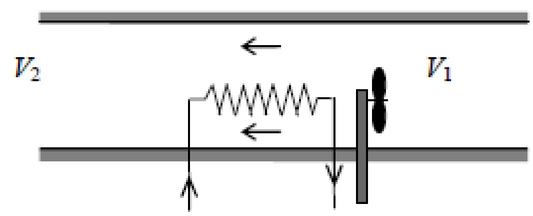
Air is expanded and is accelerated as it is heated by a hair dryer of constant diameter. The percent increase in the velocity of air as it flows through the drier is to be determined.

Assumptions: Flow through the nozzle is steady.

Properties: The density of air is given to be 1.20 kg/m^3 at the inlet, and 1.05 kg/m^3 at the exit.

$$\dot{m}_1 = \dot{m}_2$$
$$\rho_1 A V_1 = \rho_2 A V_2$$

$$\frac{V_2}{V_1} = \frac{\rho_1}{\rho_2} = \frac{1.20\ \text{kg/m}^3}{1.05\ \text{kg/m}^3} = 1.14 \quad \text{(or, and increase of } \mathbf{14\%}\text{)}$$



Therefore, the air velocity increases 14% as it flows through the hair drier.

Problem (3):

A smoking lounge that can accommodate 15 smokers is considered. The required minimum flow rate of air that needs to be supplied to the lounge and the diameter of the duct are to be determined.

Assumptions Infiltration of air into the smoking lounge is negligible.

Properties The minimum fresh air requirements for a smoking lounge are given to be 30 L/s per person.

Analysis The required minimum flow rate of air that needs to be supplied to the lounge is determined directly from

$$\dot{V}_{\text{air}} = \dot{V}_{\text{air per person}}(\text{No. of persons})$$
$$= (30\ \text{L/s}\cdot\text{person})(15\ \text{persons}) = 450\ \text{L/s} = \mathbf{0.45\ m^3/s}$$

The volume flow rate of fresh air can be expressed as

$$\dot{V} = VA = V(\pi D^2/4)$$

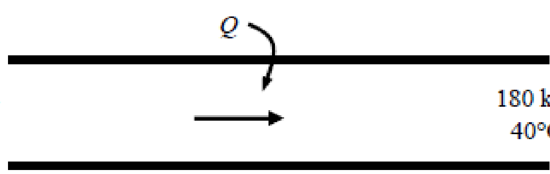
Solving for the diameter D and substituting,

$$D = \sqrt{\frac{4\dot{V}}{\pi V}} = \sqrt{\frac{4(0.45\ \text{m}^3/\text{s})}{\pi(8\ \text{m/s})}} = \mathbf{0.268\ m}$$

Therefore, the diameter of the fresh air duct should be at least 26.8 cm if the velocity of air is not to exceed 8 m/s.

Problem (4):

Air flows through a pipe. Heat is supplied to air. The volume flow rates of air at the inlet and exit, the mass flow rate, and the velocity at the exit are to be determined.



$$A_c = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times (\frac{28}{100})^2$$
$$A_c = 0.0615\ m^2$$
$$\dot{V}_i = A_c \times C_i = 0.0615 \times 5$$
$$\dot{V}_i = 0.308\ m^3/sec$$

$P_i \times v_i = R \times T_i$

$200 \times 10^3 \times v_i = 287 \times (20 + 273)$

$v_i = 0.42\ m^3/kg$

$\dot{m} = \frac{\dot{V}_i}{v_i} = \frac{0.308}{0.42}$

$\dot{m} = 0.732\ kg/sec$

$P_o \times v_o = R \times T_o$

$180 \times 10^3 \times v_i = 287 \times (40 + 273)$

$v_i = 0.5\ m^3/kg$

$\dot{V}_o = \dot{m} \times v_o = 0.732 \times 0.5$

$\dot{V}_o = 0.366\ m^3/kg$

$\dot{V}_o = A_c \times C_o$

$0.366 = 0.0615 \times C_o$

$C_o = 5.95\ m/sec.$

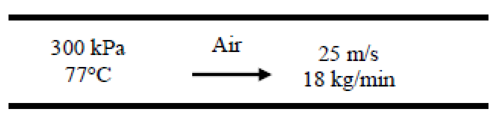
Problem (5):

Air flows steadily in a pipe at a specified state. The diameter of the pipe, the rate of flow energy, and the rate of energy transport by mass are to be determined. Also, the error involved in the determination of energy transport by mass is to be determined.

Properties: The properties of air are R = 0.287 kJ/kg.K and c_p = 1.008 kJ/kg.K
Analysis: (*a*) The diameter is determined as follows

$$v = \frac{RT}{P} = \frac{(0.287\ \text{kJ/kg.K})(77+273\ \text{K})}{(300\ \text{kPa})} = 0.3349\ \text{m}^3/\text{kg}$$

$$A = \frac{\dot{m}v}{V} = \frac{(18/60\ \text{kg/s})(0.3349\ \text{m}^3/\text{kg})}{25\ \text{m/s}} = 0.004018\ \text{m}^2$$



$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.004018\ \text{m}^2)}{\pi}} = \mathbf{0.0715\ m}$$

(*b*) The rate of flow energy is determined from

$$\dot{W}_{\text{flow}} = \dot{m}Pv = (18/60\ \text{kg/s})(300\ \text{kPa})(0.3349\ \text{m}^3/\text{kg}) = \mathbf{30.14\ kW}$$

(*c*) The rate of energy transport by mass is

$$\dot{E}_{\text{mass}} = \dot{m}(h+ke) = \dot{m}\left(c_pT + \frac{1}{2}V^2\right)$$

$$= (18/60\ \text{kg/s})\left[(1.008\ \text{kJ/kg.K})(77+273\ \text{K}) + \frac{1}{2}(25\ \text{m/s})^2\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)\right]$$

$$= \mathbf{105.94\ kW}$$

(*d*) If we neglect kinetic energy in the calculation of energy transport by mass

$$\dot{E}_{\text{mass}} = \dot{m}h = \dot{m}c_pT = (18/60\ \text{kg/s})(1.005\ \text{kJ/kg.K})(77+273\ \text{K}) = 105.84\ \text{kW}$$

Therefore, the error involved if neglect the kinetic energy is only 0.09%.

Problem (6):

Air is accelerated in a nozzle from 30 m/s to 180 m/s. The mass flow rate, the exit temperature, and the exit area of the nozzle are to be determined.

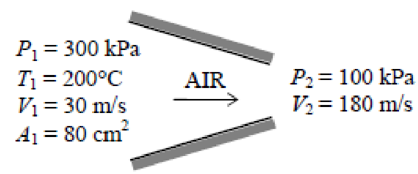
Assumptions: 1- This is a steady-flow process since there is no change with time. 2- Air is an ideal gas with constant specific heats. 3- Potential energy changes are negligible. 4- The device is adiabatic and thus heat transfer is negligible. 5- There are no work interactions.

Properties: The gas constant of air is 0.287 kJ/kg.K. The specific heat of air at the anticipated average temperature of 450 K is c_p = 1.02 kJ/kg.K.

Analysis: (a) Using the ideal gas relation, the specific volume and the mass flow rate of air are determined to be

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(473\ \text{K})}{300\ \text{kPa}} = 0.4525\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_1}A_1V_1 = \frac{1}{0.4525\ \text{m}^3/\text{kg}}(0.008\ \text{m}^2)(30\ \text{m/s}) = \mathbf{0.5304\ kg/s}$$



(*b*) We take nozzle as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{Q} \cong \dot{W} \cong \Delta\text{pe} \cong 0)$$

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \longrightarrow 0 = c_{p,ave}(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}$$

Substituting, $$0 = (1.02\ \text{kJ/kg}\cdot\text{K})(T_2 - 200^\circ\text{C}) + \frac{(180\ \text{m/s})^2 - (30\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$

It yields T_2 = **184.6°C**

(*c*) The specific volume of air at the nozzle exit is

$$v_2 = \frac{RT_2}{P_2} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(184.6 + 273\ \text{K})}{100\ \text{kPa}} = 1.313\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_2}A_2V_2 \longrightarrow 0.5304\ \text{kg/s} = \frac{1}{1.313\ \text{m}^3/\text{kg}}A_2(180\ \text{m/s}) \rightarrow A_2 = 0.00387\ \text{m}^2 = \mathbf{38.7\ cm^2}$$

Problem (7):

Steam is accelerated in a nozzle from a velocity of 80 m/s. The mass flow rate, the exit velocity, and the exit area of the nozzle are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** There are no work interactions.

Properties From the steam tables (Table A-6)

$$\left.\begin{array}{l} P_1 = 5 \text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} \upsilon_1 = 0.057838 \text{ m}^3/\text{kg} \\ h_1 = 3196.7 \text{ kJ/kg} \end{array}$$

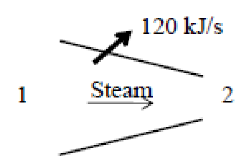
and

$$\left.\begin{array}{l} P_2 = 2 \text{ MPa} \\ T_2 = 300°\text{C} \end{array}\right\} \begin{array}{l} \upsilon_2 = 0.12551 \text{ m}^3/\text{kg} \\ h_2 = 3024.2 \text{ kJ/kg} \end{array}$$

Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. The mass flow rate of steam is

$$\dot{m} = \frac{1}{\upsilon_1} V_1 A_1 = \frac{1}{0.057838 \text{ m}^3/\text{kg}} (80 \text{ m/s})(50 \times 10^{-4} \text{ m}^2) = \mathbf{6.92 \text{ kg/s}}$$

(*b*) We take nozzle as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as



$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{Q}_{out} + \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{W} \cong \Delta pe \cong 0)$$

$$-\dot{Q}_{out} = \dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

Substituting, the exit velocity of the steam is determined to be

$$-120 \text{ kJ/s} = (6.916 \text{ kg/s})\left(3024.2 - 3196.7 + \frac{V_2^2 - (80 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)\right)$$

It yields $\quad V_2 = \mathbf{562.7 \text{ m/s}}$

(*c*) The exit area of the nozzle is determined from

$$\dot{m} = \frac{1}{\upsilon_2} V_2 A_2 \longrightarrow A_2 = \frac{\dot{m}\upsilon_2}{V_2} = \frac{(6.916 \text{ kg/s})(0.12551 \text{ m}^3/\text{kg})}{562.7 \text{ m/s}} = \mathbf{15.42 \times 10^{-4} \text{ m}^2}$$

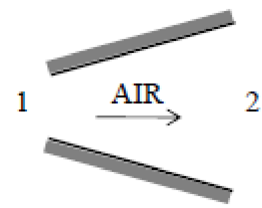
Problem (8):

Air is decelerated in a diffuser from 230 m/s to 30 m/s. The exit temperature of air and the exit area of the diffuser are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with variable specific heats. **3** Potential energy changes are negligible. **4** The device is adiabatic and thus heat transfer is negligible. **5** There are no work interactions.

Properties The gas constant of air is 0.287 kPa.m^3/kg.K

Analysis (a) We take diffuser as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as



$$\dot{Q} - \dot{W} = \dot{m} \times (h_2 - h_1) + \frac{1}{2} \times \dot{m} \times ({C_2}^2 - {C_1}^2)$$

$$0 = c_p \times (T_2 - T_1) + \frac{1}{2} \times ({C_2}^2 - {C_1}^2)$$

$$0 = 1004.5 \times (T_2 - 127) + \frac{1}{2} \times (30^2 - 230^2)$$

$$T_2 = 153°\text{C}$$

$$P_2 \times v_2 = R \times T_2$$

$$100 \times 10^3 \times v_2 = 287 \times (153 + 273)$$

$$v_2 = 1.22\ m^3/kg$$

$$\dot{m} = \frac{A_2 \times C_2}{v_2}$$

$$\frac{6000}{3600} = \frac{A_2 \times 30}{1.22}$$

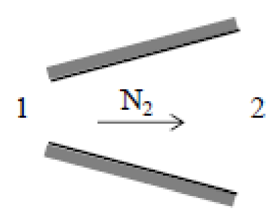
$$A_2 = 0.0678\, m^2$$

Problem (9):

Nitrogen is decelerated in a diffuser from 200 m/s to a lower velocity. The exit velocity of nitrogen and the ratio of the inlet-to-exit area are to be determined.

Assumptions: **1-** This is a steady-flow process since there is no change with time. **2-** Nitrogen is an ideal gas with variable specific heats. **3-** Potential energy changes are negligible. **4-** The device is adiabatic and thus heat transfer is negligible. **5-** There are no work interactions.

Properties: The molar mass of nitrogen is *M* = 28 kg/kmol



$$\dot{Q} - \dot{W} = \dot{m} \times (h_2 - h_1) + \frac{1}{2} \times \dot{m} \times ({C_2}^2 - {C_1}^2)$$

$$0 = c_p \times (T_2 - T_1) + \frac{1}{2} \times ({C_2}^2 - {C_1}^2)$$

<u>For Nitrogen</u>:

$$R = \frac{8314}{28} = 297\ J/kg.K$$

$$c_p = \frac{k \times R}{k-1} = \frac{1.4 \times 297}{1.4-1} = 1039.5\, J/kg.K$$

$$0 = 1039.5 \times (22-7) + \frac{1}{2} \times \left({C_2}^2 - 200^2\right)$$

$C_2 = 93.8\ m/sec$

$P_1 \times v_1 = R \times T_1$

$60 \times 10^3 \times v_1 = 297 \times (7 + 273)$

$$v_1 = 1.386\ m^3/kg$$

$P_2 \times v_2 = R \times T_2$

$85 \times 10^3 \times v_1 = 297 \times (22 + 273)$

$$v_2 = 0.97\ m^3/kg$$

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

$$\frac{A_1 \times C_1}{v_1} = \frac{A_2 \times C_2}{v_2}$$

$$\frac{A_1}{A_2} = \frac{C_2 \times v_1}{C_1 \times v_2}$$

$$\frac{A_1}{A_2} = \frac{93.8 \times 1.386}{200 \times 0.97}$$

$$\frac{A_1}{A_2} = 0.67$$

Problem (10):

Steam expands in a turbine. The change in kinetic energy, the power output, and the turbine inlet area are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible.

Properties From the steam tables (Tables A-4 through 6)

$$\left.\begin{array}{l} P_1 = 10\text{ MPa} \\ T_1 = 450°\text{C} \end{array}\right\} \begin{array}{l} v_1 = 0.029782\text{ m}^3/\text{kg} \\ h_1 = 3242.4\text{ kJ/kg} \end{array}$$

and

$$\left.\begin{array}{l} P_2 = 10\text{ kPa} \\ x_2 = 0.92 \end{array}\right\} h_2 = h_f + x_2 h_{fg} = 191.81 + 0.92 \times 2392.1 = 2392.5\text{ kJ/kg}$$

Analysis (a) The change in kinetic energy is determined from

$$\Delta ke = \frac{V_2^2 - V_1^2}{2} = \frac{(50\text{ m/s})^2 - (80\text{ m/s})^2}{2}\left(\frac{1\text{ kJ/kg}}{1000\text{ m}^2/\text{s}^2}\right) = -1.95\text{ kJ/kg}$$

(b) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{W}_{out} + \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{Q} \cong \Delta pe \cong 0)$$

$$\dot{W}_{out} = -\dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

Then the power output of the turbine is determined by substitution to be

$$\dot{W}_{out} = -(12 \text{ kg/s})(2392.5 - 3242.4 - 1.95)\text{kJ/kg} = \mathbf{10.2\ MW}$$

(c) The inlet area of the turbine is determined from the mass flow rate relation,

$$\dot{m} = \frac{1}{v_1}A_1V_1 \longrightarrow A_1 = \frac{\dot{m}v_1}{V_1} = \frac{(12 \text{ kg/s})(0.029782 \text{ m}^3/\text{kg})}{80 \text{ m/s}} = \mathbf{0.00447\ m^2}$$

Problem (11):

Steam expands in a turbine. The exit temperature of the steam for a power output of 2 MW is to be determined.

Assumptions 1- This is a steady-flow process since there is no change with time. 2- Kinetic and potential energy changes are negligible. 3- The device is adiabatic and thus heat transfer is negligible.

Properties From the steam tables (Tables A-4 through 6)

$$\left.\begin{array}{l} P_1 = 8 \text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} h_1 = 3399.5 \text{ kJ/kg}$$

Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}h_1 = \dot{W}_{out} + \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta ke \cong \Delta pe \cong 0)$$

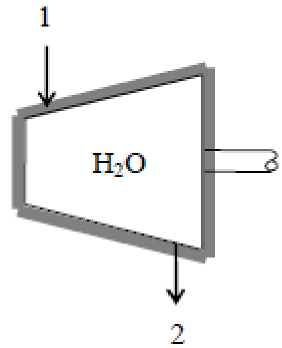
$$\dot{W}_{out} = \dot{m}(h_1 - h_2)$$

Substituting,

$$2500 \text{ kJ/s} = (3 \text{ kg/s})(3399.5 - h_2) \text{kJ/kg}$$
$$h_2 = 2566.2 \text{ kJ/kg}$$

Then the exit temperature becomes

$$\left.\begin{array}{l} P_2 = 20 \text{ kPa} \\ h_2 = 2566.2 \text{ kJ/kg} \end{array}\right\} T_2 = \mathbf{60.1°C}$$



Problem (12):

Helium is compressed by a compressor. For a mass flow rate of 90 kg/min, the power input required is to be determined.

Assumptions: 1- This is a steady-flow process since there is no change with time. 2- Kinetic and potential energy changes are negligible. 3- Helium is an ideal gas with constant specific heats.

Properties: The constant pressure specific heat of helium is

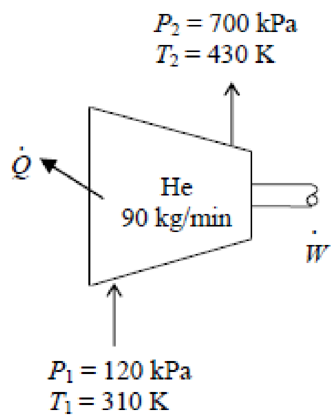
$$c_p = \frac{k \times R}{k-1} = \frac{1.67 \times (8314/4)}{1.67 - 1}$$
$$c_p = 5180 \; J/kg.K$$

Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{W}_{in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$
$$\dot{W}_{in} - \dot{Q}_{out} = \dot{m}(h_2 - h_1) = \dot{m}c_p(T_2 - T_1)$$



Thus,

$$\dot{W}_{in} = \dot{Q}_{out} + \dot{m}c_p(T_2 - T_1)$$
$$= (90/60 \text{ kg/s})(20 \text{ kJ/kg}) + (90/60 \text{ kg/s})(5.1926 \text{ kJ/kg}\cdot\text{K})(430 - 310)\text{K}$$
$$= \mathbf{965 \text{ kW}}$$

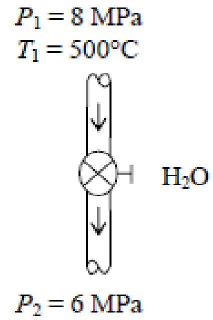
Problem (13):

Steam is throttled by a well-insulated valve. The temperature drop of the steam after the expansion is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer to or from the fluid is negligible. **4** There are no work interactions involved.

Properties The inlet enthalpy of steam is (Tables A-6),

$$\left.\begin{array}{l} P_1 = 8 \text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} h_1 = 3399.5 \text{ kJ/kg}$$



Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the throttling valve as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{system}{}^{\nearrow 0 \text{ (steady)}} = 0$$
$$\dot{E}_{in} = \dot{E}_{out}$$
$$\dot{m}h_1 = \dot{m}h_2$$
$$h_1 = h_2$$

since $\dot{Q} \cong \dot{W} = \Delta ke \cong \Delta pe \cong 0$. Then the exit temperature of steam becomes

$$\left.\begin{array}{l} P_2 = 6 \text{ MPa} \\ (h_2 = h_1) \end{array}\right\} T_2 = \mathbf{490.1°C}$$

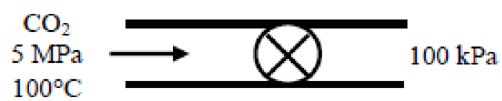
Problem (14):

Carbon dioxide flows through a throttling valve. The temperature change of CO_2 is to be determined if CO_2 is assumed an ideal gas

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer to or from the fluid is negligible. **4** There are no work interactions involved.

Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the throttling valve as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{system}{}^{\nearrow 0 \text{ (steady)}} = 0$$
$$\dot{E}_{in} = \dot{E}_{out}$$
$$\dot{m}h_1 = \dot{m}h_2$$
$$h_1 = h_2$$



since $\dot{Q} \cong \dot{W} = \Delta ke \cong \Delta pe \cong 0$.

(*a*) For an ideal gas, $h = h(T)$, and therefore,

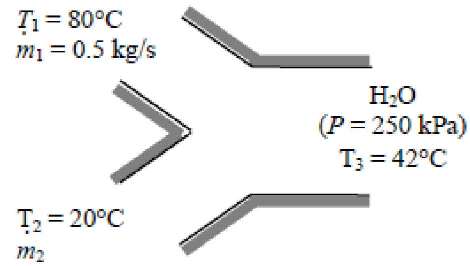
$$T_2 = T_1 = 100°C \longrightarrow \Delta T = T_1 - T_2 = \mathbf{0°C}$$

Problem (15):

A hot water stream is mixed with a cold water stream. For a specified mixture temperature, the mass flow rate of cold water is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The mixing chamber is well-insulated so that heat loss to the surroundings is negligible. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant. **5** There are no work interactions.

Properties Noting that $T < T_{sat\,@\,250\,kPa} = 127.41°C$, the water in all three streams exists as a compressed liquid, which can be approximated as a saturated liquid at the given temperature. Thus,



$$h_1 \cong h_{f@80°C} = 335.02 \text{ kJ/kg}$$
$$h_2 \cong h_{f@20°C} = 83.915 \text{ kJ/kg}$$
$$h_3 \cong h_{f@42°C} = 175.90 \text{ kJ/kg}$$

Analysis We take the mixing chamber as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as

Mass balance:

$$\dot{m}_{in} - \dot{m}_{out} = \Delta\dot{m}_{system}^{\nearrow 0 \text{ (steady)}} = 0 \longrightarrow \dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

Energy balance:

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \quad (\text{since } \dot{Q} = \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

Combining the two relations and solving for $\dot{m}_2$ gives

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

$$\dot{m}_2 = \frac{h_1 - h_3}{h_3 - h_2}\dot{m}_1$$

Substituting, the mass flow rate of cold water stream is determined to be

$$\dot{m}_2 = \frac{(335.02 - 175.90)\text{ kJ/kg}}{(175.90 - 83.915)\text{ kJ/kg}}(0.5\text{ kg/s}) = \mathbf{0.865\ \ kg/s}$$

Problem (16):

Steam is condensed by cooling water in the condenser of a power plant. If the temperature rise of the cooling water is not to exceed 10°C, the minimum mass flow rate of the cooling water required is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** There are no work interactions. **4** Heat loss from the device to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **5** Liquid water is an incompressible substance with constant specific heats at room temperature.

Properties The cooling water exists as compressed liquid at both states, and its specific heat at room temperature is $c = 4.18$ kJ/kg·°C (Table A-3). The enthalpies of the steam at the inlet and the exit states are (Tables A-5 and A-6)

$$\left.\begin{array}{l} P_3 = 20 \text{ kPa} \\ x_3 = 0.95 \end{array}\right\} h_3 = h_f + x_3 h_{fg} = 251.42 + 0.95 \times 2357.5 = 2491.1 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_4 = 20 \text{ kPa} \\ \text{sat. liquid} \end{array}\right\} h_4 \cong h_{f@20 \text{ kPa}} = 251.42 \text{ kJ/kg}$$

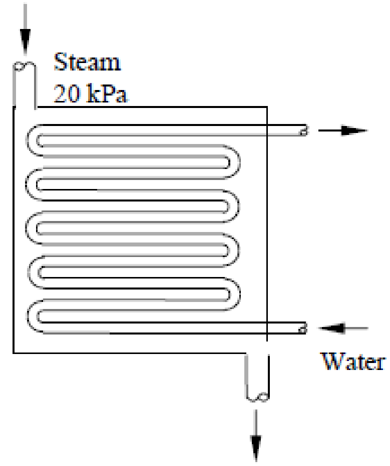
Analysis We take the heat exchanger as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as

Mass balance (for each fluid stream):

$$\dot{m}_{in} - \dot{m}_{out} = \Delta \dot{m}_{system}^{\nearrow 0 \text{ (steady)}} = 0$$

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

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_w \quad \text{and} \quad \dot{m}_3 = \dot{m}_4 = \dot{m}_s$$



Energy balance (for the heat exchanger):

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} = 0$$

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

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4 \quad (\text{since } \dot{Q} = \dot{W} = \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

Combining the two,

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

Solving for $\dot{m}_w$:

$$\dot{m}_w = \frac{h_3 - h_4}{h_2 - h_1} \dot{m}_s \cong \frac{h_3 - h_4}{c_p (T_2 - T_1)} \dot{m}_s$$

Substituting,

$$\dot{m}_w = \frac{(2491.1 - 251.42) \text{kJ/kg}}{(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})(10^\circ\text{C})} (20{,}000/3600 \text{ kg/s}) = \mathbf{297.7 \text{ kg/s}}$$

Problem (17):

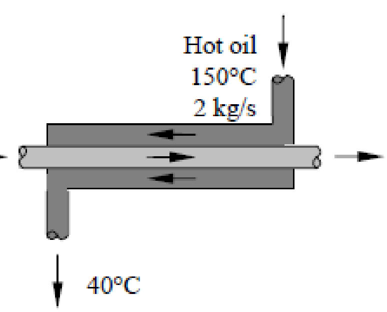
Oil is to be cooled by water in a thin-walled heat exchanger. The rate of heat transfer in the heat exchanger and the exit temperature of water is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant.

Properties The specific heats of water and oil are given to be 4.18 and 2.20 kJ/kg.°C, respectively.

Analysis We take the oil tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} = 0$$



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

$$\dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \quad (\text{since } \Delta ke \cong \Delta pe \cong 0)$$

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

Then the rate of heat transfer from the oil becomes

$$\dot{Q} = [\dot{m}c_p(T_{in} - T_{out})]_{oil} = (2 \text{ kg/s})(2.2 \text{ kJ/kg.°C})(150°\text{C} - 40°\text{C}) = \mathbf{484 \text{ kW}}$$

Noting that the heat lost by the oil is gained by the water, the outlet temperature of the water is determined from

$$\dot{Q} = [\dot{m}c_p(T_{out} - T_{in})]_{water} \longrightarrow T_{out} = T_{in} + \frac{\dot{Q}}{\dot{m}_{water}c_p} = 22°\text{C} + \frac{484 \text{ kJ/s}}{(1.5 \text{ kg/s})(4.18 \text{ kJ/kg.°C})} = \mathbf{99.2°C}$$