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ME 3322A: Thermodynamics: Fall 2014
Homework Set # 5
Due Date: September 25, 2014

	Problem # in Textbook		Answer
	7th Ed.	8th Ed.	
1	4.4	4.10	b) 1590 m^3
2	4.9	4.16	b) 5.1 cm^2
3	4.12	4.18	d1=1.732 cm; V2=33.7 m/s
4	4.24	4.24	a) 0.621 kg/s; c) 6.82 kW

PROBLEM 4.4

KNOWN: Data are provided for a crude oil storage tank.

FIND: After 24h, determine the mass and volume of oil in the tank.

SCHEMATIC & GIVEN DATA:

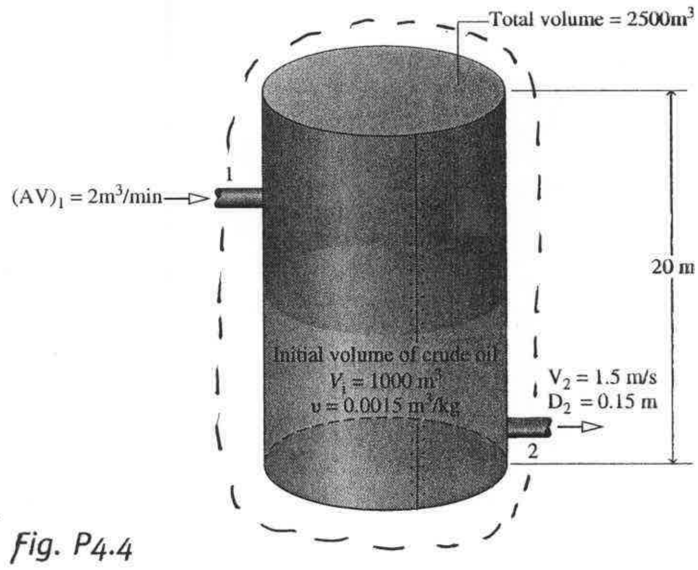


Fig. P4.4

ENGR. MODEL

1. As shown by the sketch, a control volume encloses the storage tank.
2. The specific volume of the oil is constant: $v = 0.0015 \frac{m^3}{kg}$.

(a) Mass rate balance: $\frac{dm_{cv}}{dt} = \dot{m}_1 - \dot{m}_2$, where

$$\dot{m}_1 = \frac{(AV)_1}{v} = \left(\frac{2\ m^3/min}{0.0015\ m^3/kg}\right)\left|\frac{60\ min}{1\ h}\right| = 8 \times 10^4 \frac{kg}{h}$$

$$\dot{m}_2 = \frac{A_2 V_2}{v} = \frac{(\pi D_2^2/4)(V_2)}{v} = \frac{\pi (0.15 m)^2 (1.5 m/s)}{4 (0.0015 m^3/kg)}\left|\frac{3600 s}{1 h}\right| = 6.36 \times 10^4 \frac{kg}{h}$$

$$\therefore \frac{dm_{cv}}{dt} = 1.64 \times 10^4 \frac{kg}{h}$$

Integrating

$$\Rightarrow \quad m_{cv} - m_{cv}(0) = \left(1.64 \times 10^4 \frac{kg}{h}\right)(24 h) = 39.36 \times 10^4\ kg$$

$$\left(= \frac{V_i}{v} = \left[\frac{1000\ m^3}{0.0015\ m^3/kg}\right] = 66.67 \times 10^4\ kg\right.$$

So,

$$m_{cv}(24h) = (66.67 + 39.36) \times 10^4\ kg = 1.06 \times 10^6\ kg \quad \longleftarrow m_{cv}$$

(b)

$$V(24h) = v\, m_{cv}(24h) = \left(0.0015 \frac{m^3}{kg}\right)(1.06 \times 10^6\ kg)$$

$$= 1590\ m^3 \quad \longleftarrow V$$

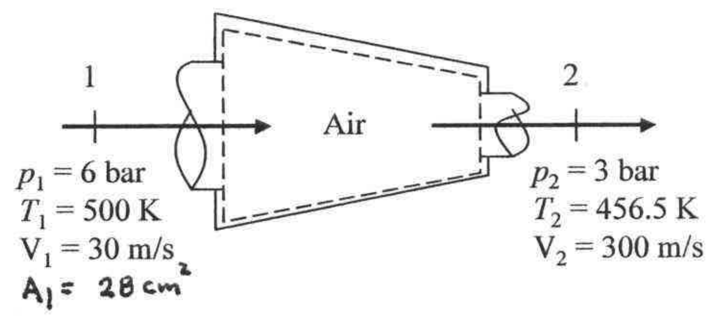
PROBLEM 4.9

4.9 Air enters a one-inlet, one-exit control volume at 6 bar, 500 K, and 30 m/s through a flow area of 28 cm^2. At the exit, the pressure is 3 bar, the temperature is 456.5 K, and the velocity is 300 m/s. The air behaves as an ideal gas. For steady-state operation, determine
(a) the mass flow rate, in kg/s.
(b) the exit flow area, in cm^2.

KNOWN: Air flows through a one-inlet, one-exit control volume with known pressure, temperature, and velocity at the inlet and exit.

FIND: Determine the mass flow rate and exit flow area.

SCHEMATIC AND GIVEN DATA:



ENGINEERING MODEL:
1. The control volume shown on the accompanying figure is at steady state.
2. The ideal gas model applies for the air.

ANALYSIS:
(a) The mass rate balance for one-inlet, one-exit, steady flow is

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

For the inlet, state 1, the mass flow rate can be determined from given data and the ideal gas equation of state.

$$\dot{m}_1 = \frac{A_1 V_1}{v_1} = \frac{A_1 V_1 p_1}{(\bar{R}/M)T_1}$$

Substituting values yields

$$\dot{m}_1 = \frac{\left(28\ \text{cm}^2\right)\left(30\frac{\text{m}}{\text{s}}\right)(6\ \text{bar})}{\left(\dfrac{8314\frac{\text{N}\cdot\text{m}}{\text{kmol}\cdot\text{K}}}{28.97\frac{\text{kg}}{\text{kmol}}}\right)(500\ \text{K})}\left|\frac{10^5\ \frac{\text{N}}{\text{m}^2}}{\text{bar}}\right|\left|\frac{\text{m}^2}{10^4\ \text{cm}^2}\right| = \underline{\mathbf{0.351\ kg/s}}$$

(b) The exit flow area can be determined from given data and the ideal gas equation of state.

$$\dot{m}_2 = \frac{A_2 \mathrm{V}_2}{v_2} = \frac{A_2 \mathrm{V}_2 p_2}{(\overline{R}/M)T_2}$$

Solving for area

$$A_2 = \frac{\dot{m}_2(\overline{R}/M)T_2}{\mathrm{V}_2 p_2} = \frac{\left(0.351\,\frac{\mathrm{kg}}{\mathrm{s}}\right)\left(\dfrac{8314\,\frac{\mathrm{N\cdot m}}{\mathrm{kmol\cdot K}}}{28.97\,\frac{\mathrm{kg}}{\mathrm{kmol}}}\right)(456.5\,\mathrm{K})}{\left(300\,\frac{\mathrm{m}}{\mathrm{s}}\right)(3\,\mathrm{bar})}\left|\frac{\mathrm{bar}}{10^5\,\frac{\mathrm{N}}{\mathrm{m}^2}}\right|\left|\frac{10^4\,\mathrm{cm}^2}{\mathrm{m}^2}\right| = \underline{\mathbf{5.1\ cm^2}}$$

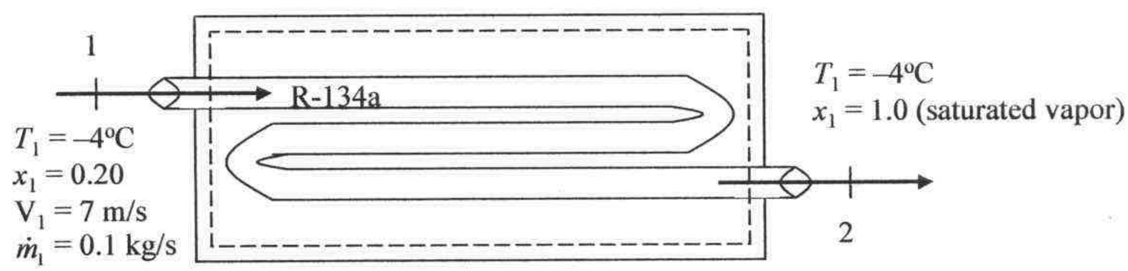
PROBLEM 4.12

4.12 Refrigerant 134a enters the evaporator of a refrigeration system operating at steady state at –4°C and quality of 20% at a velocity of 7 m/s. At the exit, the refrigerant is a saturated vapor at a temperature of –4°C. The evaporator flow channel has constant diameter. If the mass flow rate of the entering refrigerant is 0.1 kg/s, determine
(a) the diameter of the evaporator flow channel, in cm.
(b) the velocity at the exit, in m/s.

KNOWN: Refrigerant 134a flows through a constant-diameter evaporator entering as a saturated mixture at given temperature, quality, and velocity and exiting as a saturated vapor at a given temperature.

FIND: Determine the diameter of the flow channel and the velocity at the exit.

SCHEMATIC AND GIVEN DATA:



ENGINEERING MODEL:
1. The control volume shown on the accompanying figure is at steady state.

ANALYSIS:
(a) The diameter of the flow channel can be determined from the mass flow rate at the inlet, state 1

$$\dot{m}_1 = \frac{A_1 V_1}{v_1} = \frac{(\pi/4)d_1^2 V_1}{v_1} \Rightarrow d_1 = \left(\frac{4\dot{m}_1 v_1}{\pi V_1}\right)^{1/2}$$

Apply the quality relation to determine the specific volume at state 1. From Table A-10, $v_{f1} = 0.0007644$ m³/kg, $v_{g1} = 0.0794$ m³/kg. Substituting to determine specific volume

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$v_1 = 0.0007644 \text{ m}^3/\text{kg} + (0.20)(0.0794 \text{ m}^3/\text{kg} - 0.0007644 \text{ m}^3/\text{kg}) = 0.01649 \text{ m}^3/\text{kg}$$

Substituting, applying the appropriate conversion factor, and solving for the diameter

$$d_1 = \left(\frac{4\left(0.1\frac{\text{kg}}{\text{s}}\right)\left(0.01649\frac{\text{m}^3}{\text{kg}}\right)}{\pi\left(7\frac{\text{m}}{\text{s}}\right)} \left| \frac{10^4\ \text{cm}^2}{\text{m}^2} \right| \right)^{1/2} = \underline{\mathbf{1.732\ cm}}$$

(b) The exit flow velocity can be determined from the mass flow rate being equal at inlet and exit:

$$\dot{m} = \frac{A_1 \text{V}_1}{v_1} = \frac{A_2 \text{V}_2}{v_2}$$

Since the diameter is constant throughout the channel, the inlet and exit areas are the same. Since the refrigerant is a saturated vapor at the exit, from Table A-10, $v_2 = v_{g2} = 0.0794\ \text{m}^3/\text{kg}$. Solving for the exit velocity

$$\text{V}_2 = \text{V}_1\left(\frac{v_2}{v_1}\right) = \left(7\frac{\text{m}}{\text{s}}\right)\left(\frac{0.0794\frac{\text{m}^3}{\text{kg}}}{0.01649\frac{\text{m}^3}{\text{kg}}}\right) = \underline{\mathbf{33.7\ m/s}}$$

As an alternative solution, the exit flow velocity can be determined from the mass flow rate at the exit, state 2

$$\dot{m}_2 = \frac{A_2 \text{V}_2}{v_2} = \frac{(\pi/4)d_2^2 \text{V}_2}{v_2} \Rightarrow \quad \text{V}_2 = \frac{4\dot{m}_2 v_2}{\pi d_2^2}$$

The mass flow rate is the same at the inlet and the exit based on the mass rate balance for one-inlet, one-exit, steady flow. The diameter is the same at the inlet and exit since the diameter is constant through the evaporator. Since the refrigerant is a saturated vapor at the exit, from Table A-10, $v_2 = v_{g2} = 0.0794\ \text{m}^3/\text{kg}$. Substituting values and applying the appropriate conversion factor

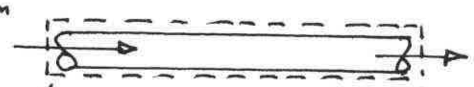
$$\text{V}_2 = \frac{4\left(0.1\frac{\text{kg}}{\text{s}}\right)\left(0.0794\frac{\text{m}^3}{\text{kg}}\right)}{\pi(1.732\ \text{cm})^2}\left|\frac{10^4\ \text{cm}^2}{\text{m}^2}\right| = \underline{\mathbf{33.7\ m/s}}$$

PROBLEM 4.23

Steam enters a horizontal pipe operating at steady state with a specific enthalpy of 3000 kJ/kg and a mass flow rate of 0.5 kg/s. At the exit, the specific enthalpy is 1700 kJ/kg. If there is no significant change in kinetic energy from inlet to exit, determine the rate of heat transfer between the pipe and its surroundings, in kW.

SCHEMATIC & GIVEN DATA:

Steam



1 — $h_1 = 3000\,kJ/kg$, $\dot{m}_1 = 0.5\,kg/s$

2 — $h_2 = 1700\,\frac{kJ}{kg}$

ENGR. MODEL:

1. The control volume shown in the sketch is at steady state.
2. For the control volume, $\dot{W}_{cv} \equiv 0$, there is no significant change in kinetic energy from inlet to exit, and $\Delta pe = 0$ (horizontal).

ANALYSIS: Reducing Eq. 4.20a

$$0 = \dot{Q}_{cv} - \cancel{\dot{W}_{cv}} + \dot{m}\left[h_1 - h_2 + \cancel{\frac{V_1^2 - V_2^2}{2}} + \cancel{g(z_1 - z_2)}\right]$$

$$\Rightarrow \dot{Q}_{cv} = \dot{m}[h_2 - h_1] = (0.5\,kg/s)(1700 - 3000)\frac{kJ}{kg}\left|\frac{1\,kW}{1\,kJ/s}\right| = -650\,kW \longleftarrow$$

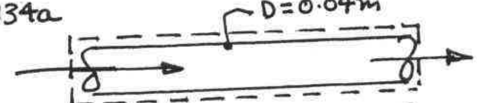
PROBLEM 4.24

Refrigerant 134a enters a horizontal pipe operating at steady state at 40°C, 300 kPa and a velocity of 40 m/s. At the exit, the temperature is 50°C and the pressure is 240 kPa. The pipe diameter is 0.04 m. Determine (a) the mass flow rate of the refrigerant, in kg/s, (b) the velocity at the exit, in m/s, and (c) the rate of heat transfer between the pipe and its surroundings, in kW.

SCHEMATIC & GIVEN DATA:

R134a

D = 0.04 m



1 — $T_1 = 40°C$, $P_1 = 300\,kPa$, $V_1 = 40\,m/s$

2 — $T_2 = 50°C$, $P_2 = 240\,kPa$

ENGR. MODEL:

1. The control volume shown in the sketch is at steady state.
2. For the control volume, $\dot{W}_{cv} \equiv 0$ and $\Delta pe = 0$ (horizontal).

ANALYSIS: (a) Using Eq. 4.4a,

$$\dot{m}_1 = \frac{A V_1}{v_1} = \frac{\left(\frac{\pi (0.04\,m)^2}{4}\right)\left(40\,\frac{m}{s}\right)}{0.08089\,\frac{m^3}{kg}}$$

Table A-12

$$\dot{m}_1 = 0.621\,kg/s \longleftarrow \text{(a)}$$

(b) $\dot{m}_1 = \dot{m}_2$ (steady state)

$$\Rightarrow \frac{A V_1}{v_1} = \frac{A V_2}{v_2} \Rightarrow V_2 = \frac{v_2}{v_1} V_1$$

$$\therefore V_2 = \left(\frac{0.10562}{0.08089}\right)(40\,m/s) = 52.23\,m/s \longleftarrow \text{(b)}$$

(c) Reducing Eq. 4.20a,

$$0 = \dot{Q}_{cv} - \cancel{\dot{W}_{cv}} + \dot{m}\left[h_1 - h_2 + \frac{V_1^2 - V_2^2}{2} + \cancel{g(z_1 - z_2)}\right]$$

$$\Rightarrow \dot{Q}_{cv} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right]$$

unit conversions on k.e. term

$$= 0.621\,\frac{kg}{s}\left[\underset{\text{(Table A-12)}}{(294.47 - 284.05)}\,\frac{kJ}{kg} + \left[\frac{(52.23)^2 - (40)^2}{2}\left(\frac{m^2}{s^2}\right)\left|\frac{1\,N}{1\,kg\cdot m/s^2}\right|\left|\frac{1\,kJ}{10^3\,N\cdot m}\right|\right]\right]$$

$$= 0.621\,\frac{kg}{s}\left[10.42 + 0.56\right]\frac{kJ}{kg}\left|\frac{1\,kW}{1\,kJ/s}\right| = +6.82\,kW \longleftarrow \text{(c)}$$