AREN 2110: Thermodynamics
Midterm 2
Fall 2004

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Name

Test is open book and notes. Answer all questions and sign honor code statement: ***I have neither given nor received unauthorized assistance during this exam***.

Signed ___Solutions___

Remember to show your work – partial credit will be given for a correct approach!

Question	Points
1	/35
2	/35
3	/30
Total	/100

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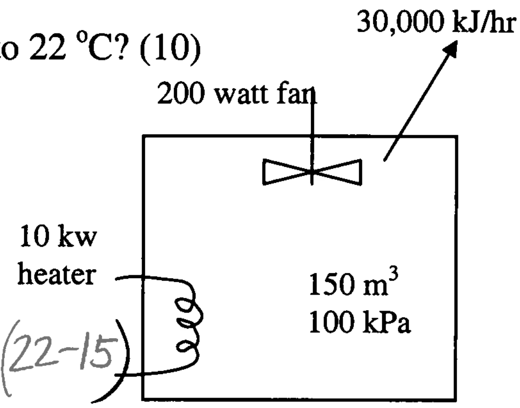
1. (35 points) A room with volume = 150 m^3, pressure = 100 kPa loses an average of 30,000 kJ/hr of heat to the surroundings continuously during the winter. The house is heated by a 10 kw electric resistance heater. A 200-watt fan that runs all the time mixes the room air. During the day when no one is home, the thermostat is set to 15 °C. At 5 PM, the thermostat set point is increased to 22 °C and the room is kept at that temperature until 8 AM the next day. Use specific heat at room temperature (300K).

a) How long will it take to warm the room air from 15 to 22 °C? (10)



$$m_{air} = \frac{P_1V_1}{RT_1} = \frac{100(150)}{0.287(288)} = 181.5\,kg$$

$$\dot{Q}(t) - \dot{W}(t) = mC_v(T_2 - T_1)$$

$$(t)\left(-\frac{30000}{3600}\,kW - (-10\,kW) - (-0.2\,kW)\right) = 181.5(0.718)(22-15)$$

$$t = 488.7\,s = \boxed{8.1\,min}$$

b) How long will the resistance heater run between 5 PM and 8 AM the next day to keep the room at 22 °C? (Neglect time to warm room.) (5)

$$10\,kW(t) = \left(\frac{30000}{3600} - 0.2\right)kW\ 15\,hr\left(3600\,\frac{s}{hr}\right)$$

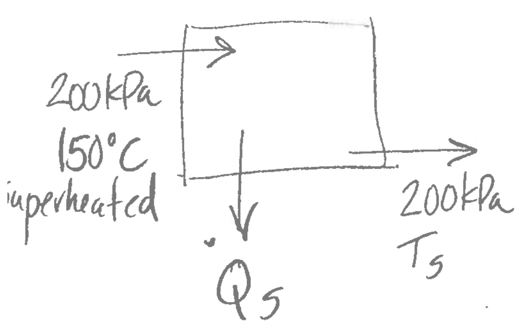
$$t = \frac{43920\,s}{3600\,s/hr} = \boxed{12.2\,hr}$$

c) If the heater turns off at 8 AM, how long will it take the house to cool to 15 °C? (10)

$$\left(-\frac{30000}{3600} - (-0.2)\right)\text{kW}\,(t) = 181.5\,\text{kg}\;0.718\,\frac{\text{kJ}}{\text{kgK}}\,(15-22)$$

$$t = \frac{112.2\ \text{s}}{60\ \text{s/min}} = \boxed{1.87\ \text{min}}$$

d) The homeowner is considering replacing the electric heater with a steam radiator. Steam enters the radiator at 200 kPa and 150 °C, and leaves as saturated liquid at the same pressure. What is the mass flow rate of steam required to keep the house at 22 °C from 5 PM to 8 AM? (10)



$$\dot{Q}_s = -\left(\frac{30000}{3600} - 0.2\right) = -8.133\ \text{kW}$$

$$-8.133 = \dot{m}\,(h_2 - h_1) \qquad h_1 = 2769.1\ \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = h_f @ 200\,\text{kPa} = 504.71\ \text{kJ/kg}$$

$$\dot{m} = \frac{-8.133\ \text{kW}}{(504.71 - 2769.1)\ \frac{\text{kJ}}{\text{kg}}} \cdot \frac{3600\ \text{s}}{\text{hr}}$$

$$\boxed{\dot{m} = 12.9\ \frac{\text{kg}}{\text{hr}}}$$

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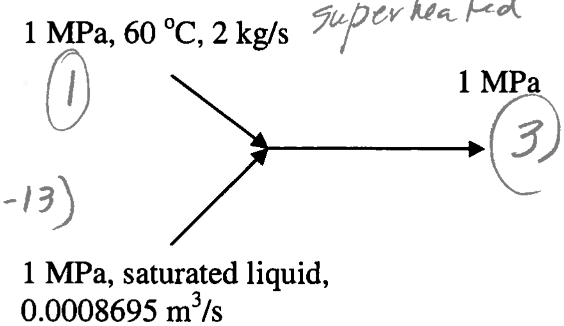
2. (35 points total) Refrigerant (R-134a) at a pressure of 1 MPa and 60 °C flows into a <u>well-insulated</u> mixing chamber at a rate of 2 kg/s. Saturated liquid R-134a at the same pressure enters the mixer at a rate of 0.0008695 m^3/s. Assume steady flow conditions.

a) What is the temperature of the refrigerant at the <u>mixer outlet</u>? (10)

$0 = \dot{m}_3 h_3 - \dot{m}_2 h_2 - \dot{m}_1 h_1$

$= 3h_3 - 1(h_2) - 2h_1$



$h_1 = 293.38$ (A-13)

$h_2 = h_f = 107.32 \frac{kJ}{kg}$

$h_3 = \frac{107.32 + 2(293.38)}{3}$

$h_3 = 231.36\ kJ/kg$

$h_f < h_3 < h_g$ @ 1 MPa

$\therefore\ T = T_s)_{1MPa} = \boxed{39.37°C}$

$\dot{m}_2 = \frac{\dot{V}_2}{v_2} = \frac{0.0008695}{0.0008700}$

$\dot{m}_2 = 1\ kg/s$

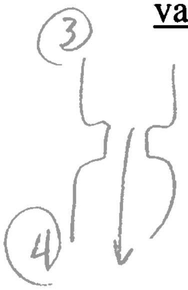
$\dot{m}_3 = 1 + 2 = 3\ \frac{kg}{s}$

b) What is the percent liquid in the refrigerant at the <u>mixer outlet</u>? (5)

$X_3 = \frac{h_3 - h_f}{h_{fg}} = \frac{231.36 - 107.32}{163.67} = 0.758$

% liquid $= 1 - x = 0.24\ \boxed{(24\%)}$

c) After mixing, the refrigerant enters an adiabatic throttling valve that reduces the pressure to 200 kPa. What is the specific enthalpy of the refrigerant at the throttling valve outlet? (5)



$$h_4 = h_3 = \boxed{231.36 \ \frac{kJ}{kg}}$$

d) What is the temperature of the refrigerant at the throttling valve outlet? (5)

$$h_f < h_4 < h_g \ @ \ 200 \text{ kPa} \quad \therefore \quad T = T_s)_{200°C} = \boxed{-10.09°C}$$

e) What percent of the R-134a is liquid at the throttling valve outlet? (5)

$$x_4 = \frac{231.36 - 38.43}{206.03} = 0.936$$

$$\% \text{ liquid} = 1 - x = 0.064 \text{ OR } \boxed{6.4\%}$$

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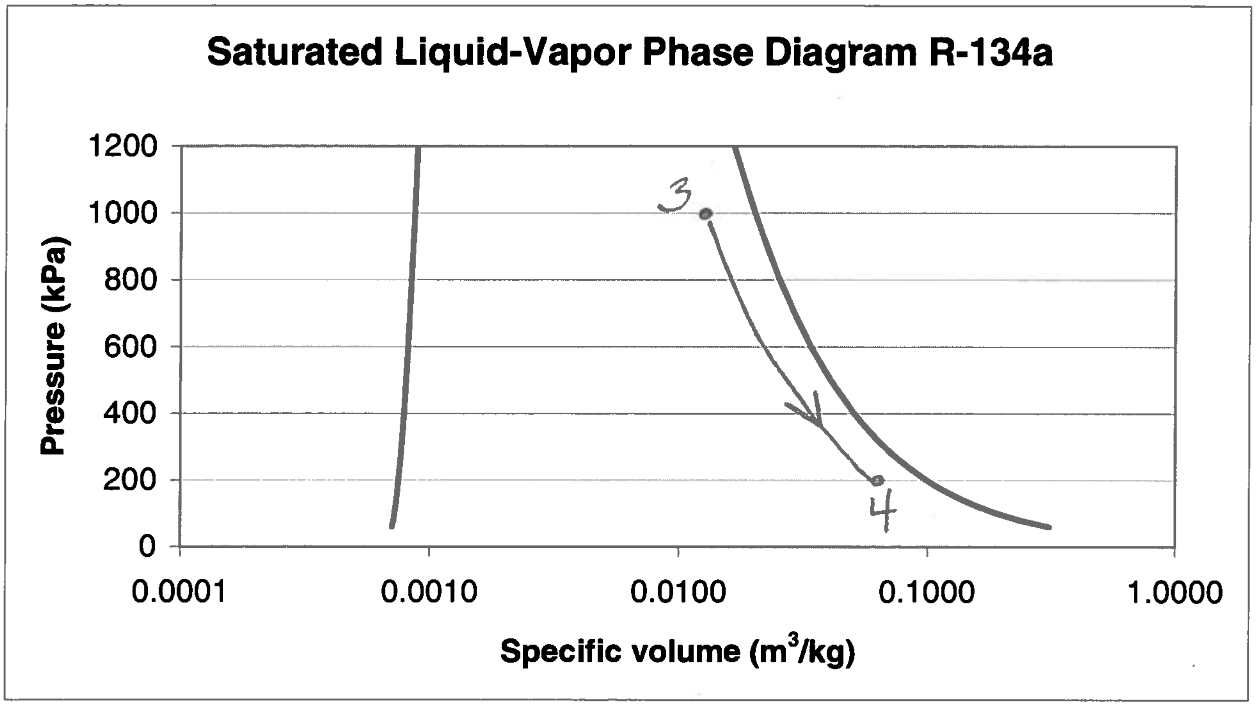
e) Draw the throttling valve process on the P-v diagram for refrigerant. (5)



1MPa $v_3 = 0.758(0.020313 - 0.00087) + 0.00087 = 0.0156 \ m^3/kg$

200kPa $v_4 = 0.936(0.099867 - 0.0007533) + 0.0007533 = 0.0935 \ m^3/kg$

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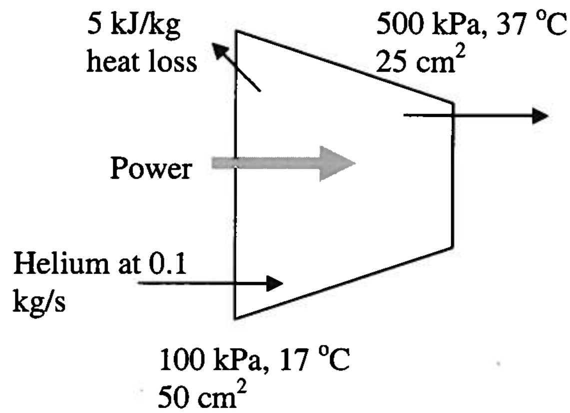
3. (30 points) Helium (He) enters a compressor at 100 kPa and 17 °C at a steady flow rate of 0.1 kg/s. The inlet area is 50 cm^2. Helium leaves the compressor at 500 kPa and 37 °C through a 25 cm^2 outlet. The compressor loses heat to the surroundings at a rate of 5 kJ/kg. Note: 1 cm^2 = 10^{-4} m^2.

a) Calculate the volumetric flow rates of He at the inlet and outlet, in m^3/s? (10)



$$\dot{V}_1 = \frac{\dot{m}}{\rho_1} = \frac{0.1\ kg/s\ (2.0769)\frac{kJ}{kg\,k}(290k)}{100kPa}$$

$$\dot{V}_1 = 0.60\ m^3/s$$

$$\dot{V}_2 = \frac{\dot{m}}{\rho_2} = \frac{0.1\ kg/s\ (2.0769)\frac{kJ}{kg\,k}(310k)}{500kPa}$$

$$\dot{V}_2 = 0.13\ m^3/s$$

b) Calculate the change in kinetic energy of the helium during compression, in kw. (10)

$$\Delta KE = \dot{m}\left(\frac{V_2^2 - V_1^2}{2000}\right)$$

$$\dot{V}_1 = V_1 A_1$$

$$V_1 = \frac{0.60\ m^3/s}{50\times10^{-4}\ m^2} = 120\ \frac{m}{s}$$

$$V_2 = \frac{0.13\ m^3/s}{25\times10^{-4}\ m^2} = 52\ \frac{m}{s}$$

$$\Delta KE = 0.1\ \frac{kg}{s}\left(\frac{52^2 - 120^2}{2000}\right)\frac{kJ}{kg}$$

$$\Delta KE = -0.58\ kW$$

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c) What is the power required for compressing the helium, in <u>kw</u>? Use room temperature value for specific heat (300K). (10)

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) + \Delta KE$$

$$-5\frac{kJ}{kg}(\dot{m}) - \dot{W} = \dot{m}(C_p(T_2 - T_1)) + \Delta KE$$

$$-\dot{W} = 0.1\frac{kg}{s}\left(5.1926\frac{kJ}{kg\,K}(37-17)K + 5\frac{kJ}{kg}\right) - 0.58\ kW$$

$$-\dot{W} = \boxed{10.3\ kW}$$