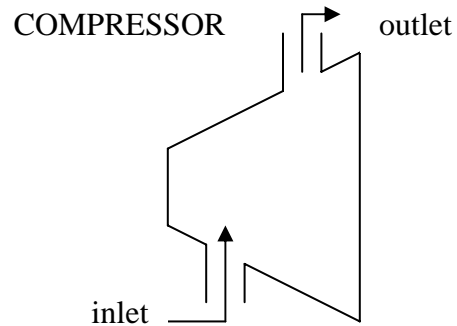


AREN 2110

First-Law Review problems

1. Air enters a compressor at 120 kPa and 40 °C and velocity of 10 m/s with an inlet area of 100 cm<sup>2</sup>. The compressor heat loss per unit mass is 50 kJ/kg.



a) What is the mass flow rate (in kg/s)?

b) What is the required input power to compress the gas to 700 kPa and 160 °C (in kW)? You can assume that kinetic (and potential) energy changes are negligible compared with other energy changes.

2. A house has a volume of  $50 \text{ m}^3$ . The house contains many appliances which draw  $1.2 \text{ kW}$  of electricity on average and shelters 3 people who produce about  $150 \text{ W}$  each. Atmospheric pressure is  $100 \text{ kPa}$ .

(a) If the house gains heat from the outdoors at a rate of  $700 \text{ W}$ , how much cooling power must be provided to keep the temperature at a constant  $22 \text{ }^\circ\text{C}$ ?

(b) If the house were sealed to eliminate any heat loss or heat gain from the outside, how long would it take for the house to heat up by  $5 \text{ }^\circ\text{C}$  with no cooling?

(c) What is the net work of the process in part b?

3. Steam flowing at 25 kg/s, 10 MPa, and 400 °C is expanded in an adiabatic turbine. At the turbine outlet the density of the wet steam is 0.728 kg/m<sup>3</sup> and the pressure is 100 kPa.

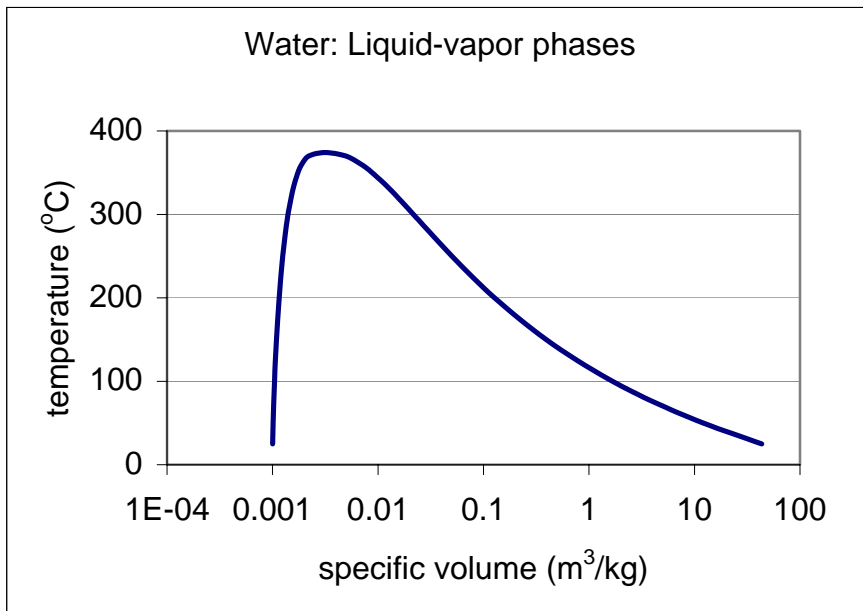
a) Find the temperature of the steam at the turbine outlet

b) Find the moisture content (% liquid) of the steam at the turbine outlet

c) Find the power output of the turbine

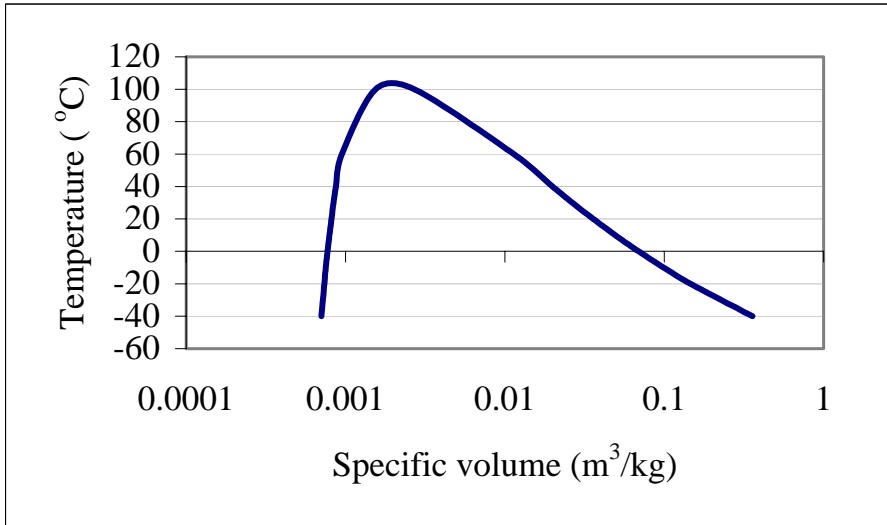
d) The wet steam is reheated after it leaves the turbine to a pressure of 8 MPa and 400 °C. How much heat is required?

e) Draw the turbine and reheat processes on the T-v diagram below showing values for temperature and specific volume for each equilibrium state



4. Refrigerant (R-134a) is condensed from saturated vapor to saturated liquid at 1 MPa in a heat exchanger. After condensation, the saturated liquid is throttled in an adiabatic device to obtain a liquid-vapor mixture at 0.14 MPa.

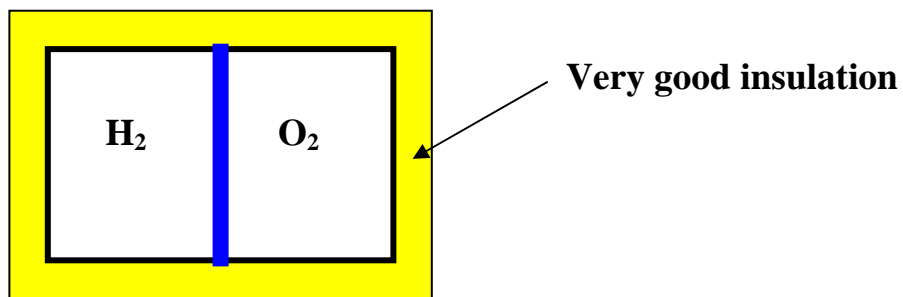
a) Show the process of condensation and throttling on the T-v diagram below including equilibrium temperatures at the beginning and end of the two-step process. (Don't forget to show process direction.)



b) What fraction of the refrigerant mass is liquid after throttling?

c) What is the net energy transfer during the two-step process.

5. A rigid-walled cylinder is divided in half by a plate that does not move.  
The cylinder is well insulated.



Given initial conditions:

- Hydrogen gas ( $H_2$ ):  $T = 100\text{ }^\circ\text{C}$ ,  $P = 600\text{ kPa}$ ,  $V = 1\text{ m}^3$
- Oxygen gas ( $O_2$ ):  $T = 20\text{ }^\circ\text{C}$ ,  $P = 400\text{ kPa}$ ,  $V = 1\text{ m}^3$

After a time, thermal equilibrium between the two compartments is reached.  
No mass is transferred across the plate, only heat.

a. Write the first law statement for the process and state all assumptions.

- b. Can you assume hydrogen and oxygen are ideal gases? Justify your assumption.
- c. Find the equilibrium temperature. Assume that the specific heat values at room temperature (300 K) are okay to use.
- d. Find the final pressure in both compartments after thermal equilibrium is reached.

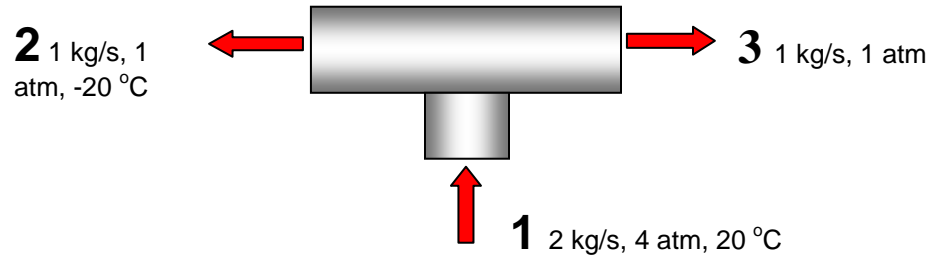
6. Hot water is cooled by air flow in a well-insulated heat exchanger. The hot water inlet temperature is  $80\text{ }^{\circ}\text{C}$ , and the outlet temperature is  $30\text{ }^{\circ}\text{C}$ . Air flows to the air inlet at  $800\text{ m}^3/\text{min}$  at a pressure of  $100\text{ kPa}$  and a temperature of  $27\text{ }^{\circ}\text{C}$ . The exit air pressure is  $95\text{ kPa}$  and temperature =  $60\text{ }^{\circ}\text{C}$ .

a) Find the mass flow rate of water that satisfies the conditions given.

b) Find the volumetric air flow rate at the air outlet.



7. The Ranque-Hilsch vortex tube is a device that produces a low-temperature gas stream that is used for cooling manufactured parts. The device is well insulated, has no external work entering or leaving the system, and has no moving parts. For this particular device, air flows in at a mass flow rate of 2 kg/s, 4 atmospheres pressure and 20 °C (293 K). The air stream is split into two equal exit streams of 1 kg/s each, both at 1 atmosphere pressure, the cooling stream temperature is -20 °C (253 K).



a) What is the temperature of the exit air at point 3?

8 A car is left with its windows closed on a summer day and the interior air reaches a temperature of  $60\text{ }^{\circ}\text{C}$ .

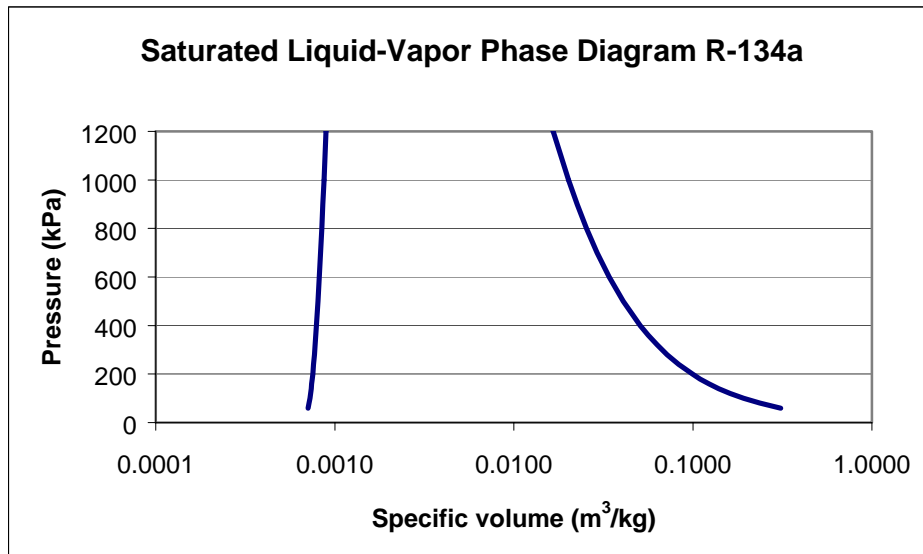
a) At what rate must heat be removed by an air conditioner in the car to bring the temperature to  $22\text{ }^{\circ}\text{C}$  in 5 minutes? Assume the windows remain closed during cooling. The volume of air in the car is  $7\text{ m}^3$ , and the air pressure =  $100\text{ kPa}$ . Solar radiation heats the car at the rate of  $10\text{ kJ/min}$  and the air conditioner has a  $100\text{-w}$  fan.

The air conditioner uses R-134a refrigerant as a working fluid. The car air is cooled by blowing it across tubes in a heat exchanger. The R-134a enters the heat exchanger pipes as a saturated mixture at  $320\text{ kPa}$  and quality =  $0.3$  and exits the exchanger as saturated vapor at the same pressure.

b) What mass flow rate of refrigerant is required to cool the car interior as for part a?

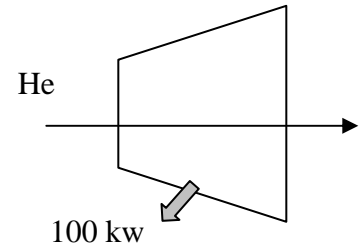
c) After evaporation in the heat exchanger, the saturated R-134a vapor is compressed to a pressure of 1 MPa and temperature = 50 °C in an adiabatic compressor. What is the power requirement for the compressor?

d) Graph the process on a P-V diagram (below) (5 points)



9. Helium enters a diffuser with a velocity of 500 m/s, pressure = 100 kPa, and temperature = 50 °C. The diffuser inlet area is 0.1 m<sup>2</sup>. The outlet temperature of the helium = 70 °C. Heat is lost from the diffuser at a rate of 100 kw.

a) What is the mass flow rate of helium for the conditions stated above?



b) What is the velocity of the helium at the diffuser outlet?

c) The outlet area = 0.2 m<sup>2</sup>. What is the pressure of the helium at the outlet?