Thermodynamics
EML 3100
Homework

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Do not print out all pages. Keep checking for changes. Complete assignment will normally be available at the end of the day of the lecture one before the homework is due.

Contents

1 Due 1/14

1. A pressurized container holds 3 kg of steel immersed in 2 L of water. The pressure inside the container is 300 kPa and the temperature 23°C.

   - What is the combined volume of the water and steel?
   - What is the combined mass?

2. A piston with a radius of 10 cm and a mass of 50 kg presses down on water inside a cylinder. The atmospheric pressure of 100 kPa also presses down on the top of the piston. What is the water pressure?

3. A manometer is filled with light oil. The difference in the height of the oil at the two sides is 10 cm. What is the pressure difference between the two sides? If the same pressure difference is measured using mercury instead of light oil, what would be the difference in height between the two sides?

4. A hundred gallon tank holds 2 lb (or rather lbm, pound mass) of oxygen. What is the specific volume v in ft^3/lbm? What is the specific volume $\bar{v}$ in ft^3/lb mol? Note: for what the book calls molecular mass, you can either take the units to be kg/kmol or lbm/lbmol. (That *defines* lbmol). The number is the same. For example, helium has a molecular mass of 4.003 lbm/lbmol as well as 4.003 kg/kmol.

2 Due 1/16

1. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) Water at 100°C and 500 kPa, in the PT diagram. Put in the temperature first.

   (b) Water at 100°C and 500 kPa, in the Pv diagram. Put in the temperature first.

   (c) Water at 100°C and 500 kPa, in the Pv diagram. Put in the pressure first.

(d) Water at 100°C and 500 kPa, in the Tv diagram. Put in the temperature first.

2. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) R-134a at 20°C and 1 MPa, in the Tv diagram. Put in the pressure first.

   (b) R-134a at –20°C and 100 kPa, in the Pv diagram. Put in the temperature first.

3. Construct the phase of the substance under the given conditions in the stated diagram. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is.

   (a) R134a, at –10°C and 100 kPa, in the Pv diagram. Put in the temperature first. State the specific volume of the substance.

   (b) R134a, at 40°C and 0.5 MPa, in the Pv diagram. Put in the pressure first. State the specific volume of the substance.

4. Construct the phase of R-134a at –10 F and 18 psia in the Pv diagram. Use the *English-units tables* in appendix A-1E to A1-32E only. Mark all lines to do it with their values. However, do not put anything more in the diagram than is needed to construct the phase. State what the phase is. State the specific volume of the substance.

   Note: You should find that the phase is compressed liquid. However, you have no compressed liquid table. I did not have time to tell you this in class, but in that case the solution is to use the saturated tables as an approximation. In doing that, make sure that you get the temperature right, and ignore the fact that you read the specific volume for the wrong pressure. The reason you can do that is that pressure makes very little difference for a liquid or solid unless it is extremely large.

3 Due 1/21

1. Find the phase of the substance under the given conditions and the requested data:

   (a) R-134a at 320 kPa and 0.071 m^3/kg. Find the temperature T and the quality x if defined.

   (b) R-134a at 60°C and 25% quality. Find the pressure P and the specific volume v.

2. Water in a piston/cylinder configuration boils at 110°C. There is standard atmospheric pressure above the piston and the piston has a mass of 30 kg. What is the diameter of the piston?

3. A piston/cylinder combination contains R-134a at $x = 1$ and 1017.1 kPa. Find the exact phase it is in, the temperature, and specific volume.

(a) The piston is then pulled up in an isothermal process until the distance from the bottom of the cylinder is doubled. Construct the final phase in the Tv diagram. Label the lines with their values. Find the final temperature, pressure, specific volume, and quality if defined.

(b) Repeat if *instead* the piston is pushed into the cylinder until it is twice as close to the bottom of it as it was.

4. A steel tank with a volume of 5 m^3 contains saturated R-134a at 10°C. The liquid is then boiled away and disappears at 40°C. What is the final pressure? How much liquid was boiled away? (In other words, what was the part of the mass that was initially liquid?)

4 Due 1/23

1. Determine whether the ideal gas approximation is reasonable for the following conditions. State why or why not. Determine the phase if needed.

   (a) Oxygen at 30°C, 3 MPa

   (b) Methane at 30°C, 3 MPa

   (c) Water at 30°C, 3 MPa

   (d) R-134a at 30°C, 3 MPa

   (e) R-134a at 30°C, 100 kPa

2. A constant pressure cylinder/piston configuration holds 2 m^3 of air at 5°C and standard atmospheric pressure. What is the mass of the air? If the air is now cooled until the volume is half the original one, then what is the final temperature of the air in degrees centrigrade?

3. A rigid tank holds 4 m^3 of air at 6 bar and 100°C. To cool it down a bit, 2 kg of air is allowed to escape. This lowers the temperature by 25°C. What is the final pressure?

4. A rigid tank A of volume 2 m^3 is connected by a valve to another tank B with twice the volume. In state 1, tank A holds nitrogen at 100 kPa and 250 K, and tank B nitrogen at 200 kPa and 300 K. The valve is opened and the combined tanks come to a uniform state 2 at a temperature of 280 K. What is the pressure in the tanks then? (Note: If you want, you can treat the two tanks in state 2 as one combined volume holding one combined mass.)

5 Due 1/28

1. A constant pressure cylinder contains 2 kg water at 4 bar that is cooling down. The water is just starting to condense at the start of the process. At the end of the process the volume is half that at the start.

(a) Find the initial phase.

(b) Construct the final phase in the Pv diagram. Label all lines to do so with their values. Do not put more in the diagram than is needed to construct the phase.

(c) Find the final temperature and volume to 5 digits accurate.

(d) Find the work done by the substance in the process.

(e) Show the work done graphically in the Pv diagram. How about the sign?

2. A steel container with a volume of 300 L contains 3kg of water at 20 °C. The water is heated. What is the temperature at which all liquid water is gone, to five digits accurate? What is the work done by the water in the process? Show the process in the Pv diagram and so identify the work done graphically.

3. A piston-cylinder configuration contains 2 kg of air at standard atmospheric pressure and 25°C. The piston is held by a linear spring. The air is now heated until the volume becomes 4 m^3 and the pressure 200 kPa. What is the final temperature in °C? What is the work done in the process? Show the work done also graphically in the PV diagram.

4. A piston cylinder combination contains 0.2 m^3 of nitrogen at 5 bar and 25°C. The nitrogen is now allowed to expand to the ambient pressure of 100 kPa. It can be assumed that the expansion is sufficiently slow that the temperature remains at 25dg. Find the work done by the nitrogen in the process. Show the process in a very neat PV diagram and graphically indicate the work.

6 Due 1/30

1. A piston cylinder combination contains 2 kg of air at the ambient temperature of 25°C and at the unknown ambient pressure. To provide a source of cooling on this hot Florida day, the piston is now pulled up until the air reaches a temperature of -100°C. It can be assumed that the process is a polytropic one with $n = 1.4$. What is the work that must be done *on* the air in the cylinder to pull up the piston and produce the cold air? The piston must also do work on the air outside the cylinder, which remains at the ambient pressure. What is the expression for that work? You do not have to compute this work, though a smart student could do it.

2. Two cubic meters of a gas at 200 kPa expands polytropically with $n = 5/3$ to standard atmospheric pressure. What is the work done by the gas in the process?

3. Air in a piston/cylinder combination with an initial volume of 1 m^3 is initially kept at a pressure of 150 kPa by the weight of the piston and the atmospheric pressure. It expands to 2 m^3, at which time the piston hits against a linear spring. The air then continues to expand to 4 m^3 while the pressure increases to 300 kPa due to the increasing spring force. Find the work done by the air in the complete process. Draw the PV diagram very neatly and graphically show the two parts of the work done by the air.

4. A piston cylinder combination initially contains 5 L of R-134a at -10°C. Because the piston is light and initially floats on the R-134a, the initial pressure inside the cylinder is the ambient 100 kPa one. However, if the volume would expand to 6 L, the piston would hit some stops and the volume could no longer increase any further. Now the cylinder is heated until the R-134a reaches 50°C. Does the piston hit the stops? How do you know? What are the final pressure and volume? What is the work done by the R-134a in the process? Give a Pv phase construction of the initial phase, drawing P first. For the later phases 1a and 2, you can use your knowledge about the earlier phases to locate them. Show the process line as a thick line in the Pv diagram. Also show the work graphically in the diagram.

7 Due 2/11

1. Construct the phases of the below states in *both* the Pv and Tv diagrams, labeling all lines with their values. *Make a separate diagram for each case, six diagrams in total.* Find the missing properties of T, P, v, u, h and x if applicable.

   (a) Water at 5000 kPa, $u = 800$ kJ/kg

   (b) Water at 5000 kPa, $v = 0.06$ m^3/kg

   (c) R-134a at 34°C, $v = 0.01$ m^3/kg

2. Water in a rigid container at 300°C, 1200 kPa has a mass of 0.75 kg. The water is cooled to 300 kPa. Find the final temperature, the work and the heat transfer in the process. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Show a Pv diagram of the process. So your solution must have a total of three diagrams.

3. There is 2 kg of liquid water at 300 kPa and 20°C in piston/cylinder combination. A linear spring on the piston exerts a force such that when the water is heated the pressure reaches 1 MPa with a volume of 0.2 m^3. Find the final temperature and the heat transfer in the process. Show a Pv diagram of the process.

4. A constant-pressure piston/cylinder has 2 lbm of water at 1100 F and 2.26048 ft^3. It is now cooled to occupy 1/10 of the original volume. Find the heat transfer in the process. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Show a Pv diagram of the process.

8 Due 2/13

1. Hot 500°C copper with a volume of 2 L is dumped in 200 L light oil initially at 20°C. Assuming no heat transfer with the surroundings, what is the final temperature?

2. Carbon dioxide changes in temperature from 500 to 1300 K. Find the change in specific internal energy, in kJ/kg,

(a) using a constant C_v from table A-2(a)

(b) using the C_v evaluated from equation in A-2(b) at the average temperature of 900 K.

(c) using the C_v evaluated from the equation in A-2(c) at the average temperature of 900 K.

(d) Using the values listed in table A-20

3. Air in a piston cylinder at 600 kPa, 290 K has a volume of 0.01 m^3. An isobaric process produces 18 kJ of work. Find the final temperature of the air and the heat transfer input.

4. Air is kept inside a cylinder by a piston constrained by a linear spring. Initially there is 3 kg of air at 300 K and 160 kPa. It is then heated to 900 K to a final volume of twice the initial volume. Plot the process in a Pv diagram. Find the work done by the substance and heat added.

9 Due 2/18

1. A steel tank contains 2 kg of carbon dioxide gas at 100 kPa, 1000 K that is heated to 1400 K. Find the heat transfer using
   1. the heat capacity from Table A-2(a);
   2. the heat capacity at 1000 K from Table A-2(b);
   3. the heat capacity at the average temperature from Table A-2(c);
   4. the ideal gas properties from Table A-20.

   Comment on the accuracy of the first three methods.

2. An insulated steel tank is divided into two parts of 3 m^3 each by an initially locked piston. Side A has air at 200 kPa, 300 K, and side B has air at 1.0 MPa, 1000 K. The piston is now unlocked so it is free to move, and it conducts heat so the air comes to a uniform temperature $T_A = T_B$. Find the mass in both A and B, and the final T and P.

3. A piston/cylinder contains helium at 500 K and 1200 kPa. It expands polytropically with $n = 1.667$ to a pressure of 100 kPa. Find the final temperature, the specific work and specific heat transfer in the process.

4. Air in a piston/cylinder combination is being heated at a rate of 50 kW. At a certain time, the temperature is 25°C, the pressure 200 kPa, the volume 2 m^3 and the rate of volume change $\dot{V}$ is 0.2 m^3/s. What is the power produced by the air and what is the rate of change in temperature in °C/s at that time?

10 Due 2/20

1. A stream of 0.3 kg/s of water enters an insulated nozzle at 250°C, 500 kPa with negligible velocity. The water exits at 275 kPa with a velocity of 800 m/s. Find the required diameter of the exit area of the nozzle. Construct all phases that are not given in a Pv diagram. Label the lines with their values.

2. An compressor takes in normal nitrogen at 200 kPa, 27°C and sends it at 1000 K and 2 MPa into a heat exchanger. It exits the heat exchanger at 300 K. Find the specific work done by the compressor and the specific heat removal in the heat exchanger. Make an appropriate approximation for the type of process in the compressor and another one for the one in the heat exchanger. Both assumptions are mentioned in the list of thermo devices. Assume that nitrogen is an ideal gas.

3. A stream of 2 kg/s of refrigerant R-134a enters a condenser at 600 kPa an 30°C. It exits as saturated liquid at 20°C. What is the cooling capacity in kW of the condenser? Construct all phases that are not given in a Pv diagram. Label the lines with their values.

4. Compressed liquid water at 10 MPa and 40°C enters a constant pressure steam generator through a 20 mm diameter pipe at the rate of 5 L/s. The water exits the generator at 350°C through a pipe of the same diameter. Show in the Pv diagram that the final phase of the water is indeed steam and find the rate of heat transfer to the water. Show a Pv diagram of the process.

11 Due 2/25

1. An adiabatic turbine receives steam from two boilers. One boiler provides 10 kg/s at 5 MPa, 600°C and the other provides 20 kg/s at 800 kPa, 500°C. The steam exits the turbine at a pressure of 100 kPa, with a quality of 90%. Find the final temperature and the produced power.

2. A turbine takes in 2 kg/s neon at 27°C and 200 kPa with negligible velocity. The produced work is 75 kW and 30 kW of heat leaks into the turbine from the surroundings. The neon exits at 100 kPa and 230 K. Find the exit velocity of the neon.

3. Engine coolant (glycerine) enters the radiator of your car with a temperature of 100°C and exits it at 50°C. If the coolant must remove 30 kW of heat, what must be its mass flow rate through the radiator? If the heat is carried off by ambient air at about one atmosphere that has a temperature of 15 degrees before flowing through the radiator and 35 degrees after it, what is the volume flow of the air?

4. An adiabatic mixing chamber takes in two streams of water both at the ambient pressure of 100 kPa. On stream is 2 kg/s water at 50°C, and the other is water at 200°C. Pressure losses in the mixing chamber can be ignored, and the water comes out as saturated liquid. What is the mass flow rate of the incoming stream at 200°C? Construct all phases that are not given in a Pv diagram. Label the lines with their values. .

12 Due 2/27

1. A stream of 0.5 kg/s R 134a at 20°C and $x = 0.9$ enters a mixing chamber through a throttle and is then mixed with a 2 kg/s stream at 100°C and 500 kPa. The R 134a exits the mixing chamber at 50°C and 500 kPa. Construct all phases that are not given in a Pv diagram. Label the lines with their values. Find the heat going into the mixing chamber.

2. If high pressure steam is needed for some purpose in a power generation plant, it is often bled off from the high pressure side of the turbine. This is called cogeneration. Assume a well insulated turbine takes in 50 kg/s of steam at 10 MPa and 600°C, and that 10 kg/s at 400 kPa and 200°C is bled off, while the remaining steam exits at 100 kPa and a quality of 0.8. Construct the phase of the bled-off steam in the Tv diagram and so verify that it is indeed still steam. Find the power the turbine generates, and compare it to the power it would generate if no steam was bled off.

3. A stream of 2 kg/s of neon at 200°C and 100 kPa mixes with a stream of 3 kg/s of neon at 100°C and 100 kPa. The neon exits at 100 kPa and 50 kW of heat leaks out to the surroundings. Find the exit temperature.

4. Water enters a turbine with a velocity of 150 m/s at 200 kPa and 300°C at a rate of 5 kg/s. It exits the turbine at a pressure of 100 kPa and low velocity. The turbine produces 4 MW of power and loses 400 kW of heat to its surroundings. Construct and name the phase at the entrance in a Pv diagram, narrow down the exit conditions, construct and name the phase at the exit using a Pv diagram and find the exit temperature and quality if defined. Ignore the height difference between the entrance and exit.

13 Due 3/18

1. Some car driving 60 mph on the highway uses 8 L of fuel per hour. The heating value HV of the fuel is about 42.4 MJ/kg and the density is 750 kg/m^3. If the thermal efficiency of the engine is 25%, then what is the power available at the crankshaft axis in bhp?

2. For each of the cases below determine if the heat engine satisfies the first law, and *if* it does, if it satisfies the second law, and *if* it does, whether it is now a useful heat engine.

$\dot{Q}_H$	$\dot{Q}_L$	$\dot{W}$	1st law?	2nd law?	useful?
5	4	3			
5	3	2			
5	5	0			
5	0	5			
0	5	–5			
5	10	–5			

3. For each of the cases below determine if the heat pump or refrigeration cycle satisfies the first law, and *if* it does, if it satisfies the second law, and *if* it does, whether it is now a useful heat pump or refrigeration cycle.

$\dot{Q}_H$	$\dot{Q}_L$	$\dot{W}$	1st law?	2nd law?	useful HP?	useful RC?
5	4	3				
5	3	2				
5	5	0				
5	0	5				
0	5	–5				

4. Water at 25°C and 100 kPa enters an isobaric heat exchanger at a rate of 5 kg/s and is heated into saturated steam without droplets in it. The heat is provided by a heat pump with a coefficient of performance of 3. Determine the amount of power required by the heat pump.

14 Due 3/25

1. You want to keep your house at 25°C. What is the maximum coefficient of performance of a heat pump if it is 10°C outside? What is it if it is -20°C outside? Assume that if it is -20°C outside, the amount of heat needed is four times the amount of heat needed when it is 10°C outside. How much more electricity would an ideal heat pump then require if it is -20°C outside instead of 10°C? Also, if it is 10°C outside, then how much more power would a resistance heater require compared to an ideal heat pump?

2. Suppose that you have a basin of 35°C warm water that you use to run a heat engine that cools its substance with air at 20°C. What is the maximum efficiency of the heat engine? What is the work you get out of each kJ of heat extracted from the basin? Repeat for the case that the water is at 100°C. Comment on why efficient car engines run so hot.

3. Assume that your car engine burns 2 kg of fuel per hour in its cylinders at a temperature of 1500 K. The heating value of the fuel is 50 MJ/kg. Assume that the combustion heat is the equivalent of the heat $\dot{Q}_H$ in a heat engine. Assume that the engine rejects heat at an average temperature of 750 K through its exhaust, radiator, etcetera. Find the maximum amount of horsepower the engine can provide. But don't think you are going to get it from your car.

4. A Carnot refrigerator uses helium as refrigerant. It is 5°C inside the fridge and 20°C in the kitchen. The helium pressure decreases from 100 kPa to 90 kPa during the heat extraction from the fridge. How much heat is extracted from the fridge per kg of helium in each cycle, and what is the work required?

15 Due 3/27

1. Construct the phase of

   1. water if the entropy is 7.70 kJ/kg K, P = 25 kPa, using the Ts diagram. Then find the values of the enthalpy, T, and x if defined.

   2. water, if u = 3400 kJ/kg and P = 10 MPa, using the Pv diagram. Then find the values of T, s, and x if defined

   In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points.

2. A Carnot-cycle heat pump uses R-134a as refrigerant. Heat is absorbed from the outside at -10°C. It is delivered to the heated space at 40°C. Assume that the R-134a enters the hot-side heat exchanger as saturated vapor and exits it as saturated liquid.

   1. Show the cycle in the Ts diagram. List the entry to the hot side heat exchanger as 1, the exit of it as 2, and so on.

   2. Find the quality of the R-134a at the beginning and end of the isothermal heat addition process at -10°C.

   3. Determine the coefficient of performance for the cycle.

3. Two kilogram R-134a in a piston/cylinder at 40°C, 1000 kPa is expanded in a reversible isothermal process to 100 kPa.

   1. Construct the initial phase of the R-134a in both the Ts and Pv diagrams. Draw temperature first. In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used.

   2. Add the final state to the diagrams and then draw the process in them as a fat curve. (A "curve" might have straight parts.)

   3. Find the work and heat transfer.

4. Water in a piston/cylinder at 400°C, 2000 kPa is expanded in a reversible adiabatic process. The specific work is measured to be 417 kJ/kg out.

   1. Construct the initial phase of the water in both the Ts and Pv diagrams. In each diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used. Watch it: the temperature of the critical point is 374.1°C, less than 400°C.

   2. Find two intensive variables for the final state. Then use table A-4, not A-5, to find the saturated value(s) needed to figure out the phase.

   3. Show the final state, and also the process line as a fat curve, in the two diagrams.

   4. Find the final pressure and temperature.

16 Due 4/1

1. A solar-heated house uses a box of dry sand of $3 \times 4 \times 0.5$ m to store solar heat. If during the night the sand cools from 35°C to 20°C, then how much heat is released to the 18°C isothermal house? What is the entropy generated in the total system by this process?

2. Three kg of liquid lead initially at 500°C is poured into a form. It then cools at constant pressure down to room temperature of 20°C as heat is transferred to the room. The melting point of lead is 327°C and the enthalpy change h_{if} between saturated solid and saturated liquid lead at 100 kPa is 24.6 kJ/kg. The specific heat of liquid lead is 0.16 kJ/kg K and for solid lead 0.13 kJ/kg K (from table A-3(b), rounded). Calculate the net entropy generated by the complete process in the complete system including the room.

3. Carbon dioxide at 400K and 30 kPa in an insulated cylinder is compressed to 625 kPa in a reversible process. Calculate the specific work and final temperature using

    1. the exact data from table A-20.
    2. constant specific heats, taken from table A-2(a). Do *not* use the polytropic formulae to find the work and temperature. Use the expression for the entropy change with constant specific heats instead to find the temperature, then use the first law.

    Compare the results.

4. Helium is reversibly and isothermally compressed from 100 kPa and 20°C to 600 kPa, and then it expanded reversibly adiabatically back to 100 kPa.

    1. Show this two-step process as a fat curve in both the Ts and Pv diagrams. Label the states as 1, 2, and 3.
    2. Explain why the first process is polytropic with $n = 1$ and the second with $n = 1.667$.
    3. Use the first law and heat formulae to get the specific work in the first step from 1 to 2.
    4. Compute the same work directly from the appropriate polytropic work formula and compare results.
    5. Unlike what you did in question 3.2, now use the polytropic formulae to get the final temperature T_3. It should be 143.06 K.
    6. Unlike what you did in question 3.2, now use the polytropic work formula to find the specific work in the second step from 2 to 3.

17 Due 4/3

1. Two kg of hot saturated water vapor is in a cylinder closed by a weighted piston that pressurizes it to 200 kPa. Since the surroundings are at 20°C, the hot water cools down until the volume becomes half the original one.

   (a) Construct the final phase of the water in the Pv diagram. In the diagram, list no more than is needed to construct the phase, but do list the values of the curves/points used.

   (b) Find the work done by the water.

   (c) Find the heat that has leaked out of the water.

   (d) Find the net entropy generated in the system and surroundings in the cool-down process.

2. A piston-cylinder contains 20 L of water at 200 kPa and 200°C. The piston is now pushed into the cylinder at a rate so that PV stays constant, while the pressure increases to 800 kPa. The heat that leaks out of the cylinder ends up in the 20°C surrounding room.

   (a) Construct the initial and final phases of the water in separate Pv diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used. In a third Pv diagram, show the process as a fat curve.

   (b) Find the work done by and heat added to the water in the process.

   (c) Does the total process satisfy the second law of thermo? Is it reversible?

3. Two kg of air at the ambient pressure of 100 kPa and at the ambient temperature of 15°C is confined within a steel container. A heating element within the tank now adds 100 kJ of heat to the air, and the air then ends up at 75°C. Find the net entropy generated by the process and comment on whether this process is possible. Use table A-2(a) values, do not use table A-17. If this question makes sense to you, please explain.

4. One kg of methane gas at 100 kPa and 20°C is compressed isentropically to 800 kPa. Calculate the final temperature using the polytropic relations. Then calculate the work done in the process. Calculate the work done directly, do *not* use the first law to do it. Assume constant specific heats from table A-2(a) (even though that is a lousy approximation).

18 Due 4/8

1. A plane flies at an height where the ambient temperature is -45°C and the pressure 60 kPa with a true airspeed of 900 km/h. Air is flowing into an adiabatic jet engine diffuser through an entrance area of 1 m^2 with a speed of 900 km/h and slows down to

20 m/s at the end of it. What is the temperature at the end of the diffuser, and what is the maximum possible pressure there? Use table A-17 values, not table A-2 ones.

2. An isothermal compressor compresses R-134a at 0°C and 200 kPa to saturated vapor. Construct the initial phase in the Pv and Ts diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used. Also show the final state in the diagrams, and the process between the two as a fat line. Find the specific heat transfer and work. Show the areas in the Pv and Ts diagrams that are equal to these. (The work in a control volume is $\int v\,\mathrm{d}P$.)

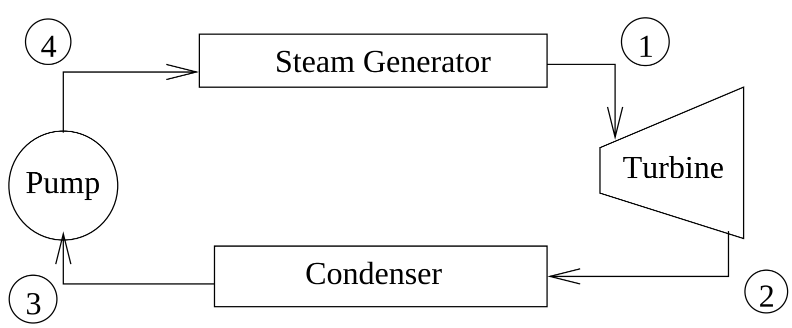
3. Three kg/s of R-134a at 500 kPa flows as saturated vapor into an isobaric reversible heat exchanger where it is heated to 60°C. Show the process in a Ts diagram. There should be no need to construct the phases. Compute the heat that is added to the R-134a. Now assume that this heat is provided by a reversible heat pump that takes in heat from the surroundings that is at 300 K. What is the power needed by the heat pump?

   Warning: do *not* try to use the Carnot formula for the COP of the heat pump. It does not work since the high temperature, (the temperature of the R-134a), is not constant but varies from about 16°C to 60°C. Instead, write the second law for the combined system and use the fact that the generated entropy in the combined system is zero, because everything is reversible. That will give you the low heat flow. Then use the first law for the heat pump to find the work.

4. A completely reversible air heater receives a flow of 2 kg/s air at 400 K and 200 kPa and the air leaves at 600 K and 100 kPa. The heater pumps heat at a rate of 50 kW out of a reservoir at 500 K, while it pumps the remaining heat out of the environment at 300 K. What is the heat obtained from the environment and what is the work needed to keep this reversible heater running?

19 Due 4/10

1. Consider the steam powerplant



   where $P_1 = 20$ MPa, $T_1 = 700$°C, $P_2 = 20$ kPa, and $T_3 = 40$°C. Make typical approximations for each component as needed.

- Explain why phase 1 must be superheated. Find phases 2, 3, and 4 in separate Ts diagrams. In the diagrams, list no more than is needed to construct the phase, but do list the values of the curves/points used.
- Find the specific works out of the turbine and into the pump.
- Find the thermal efficiency of the cycle.
- Considering the average temperatures in the boiler and condenser, does the efficiency you get seem reasonable, too high, too low?

2. R-134a at 1MPa and 30°C passes through an adiabatic expansion valve in which the pressure decreases to standard atmospheric pressure. Construct the initial phase in the Ts diagram. Then construct the final phase in a separate Ts diagram, find the final quality if defined, and then the entropy generated.

3. Steam at 15 kPa and a quality of 90% enters a constant pressure condenser at a rate of 3 kg/s and exits it as saturated liquid. The heat is transferred to cooling water with an average temperature of 17°C. What is the entropy generated?

4. Air at 1000 kPa and 500 K enters an isobaric heat exchanger at a rate of 0.2 kg/s and exits at 300 K, having been cooled down by the ambient air at 300 K. Find the total rate of entropy generation. Use constant specific heats from table A-2(a), not table A-17.

20 Due 4/15

1. You want to cool your cryogenics experiment by pumping pressurized liquid nitrogen through it. What is the power needed for a reversible pump that pressurizes 20 g/s of liquid nitrogen at 77.3 K from 200 kPa to 1MPa? Make appropriate approximations. Note: Under standard atmospheric pressure, liquid nitrogen boils at 77.3 K, and then has a specific volume of the liquid equal to 0.001240 m^3/kg and of the vapor 0.21639 m^3/kg.

2. A typical specific heat ratio for the hot combustion gases entering the turbine of a jet engine is 1.25. For the gas constant, just use the one for air. Assume that the gases enter the turbine at 640 kPa and 927°C, and exit at the ambient pressure of 100 kPa at a rate of 2 kg/s. Also assume that the specific heat ratio is constant going through the turbine, and that the turbine is adiabatic and reversible. Find the exit temperature, power, and heat flow. *Do not compute any volumes, specific or not, when solving this question.*

3. An reversible isobaric heat exchanger heats a stream of carbon dioxide at 100 kPa from 300 to 500 K. It takes in heat from a 600 K reservoir. Find the work required, the heat taken from the reservoir, and the overall entropy generation.

4. A 0.25 kg/s stream of oxygen at 200 kPa and 17°C and a separate 0.6 kg/s stream of nitrogen at 150 kPa and 500 K enter an insulated "coflowing heat exchanger".

There is heat conduction through the pipe wall separating the oxygen flow from the surrounding nitrogen flow, so the oxygen will heat up and the nitrogen cool down. The heat exchanger is long enough that oxygen and nitrogen come out with the same temperature. Determine that exit temperature and find the entropy generated by the process. Use constant specific heats from table A-2(a), not A-17—A-25. Make a typical approximation for heat exchangers for each stream.

21 Due 4/24

1. A compressor takes in saturated steam (free of water droplets) at 1000 kPa and compresses it to 17.5 MPa and 650°C.

   (a) Show the process in both the Pv and Ts diagrams. Also show the process of the comparable ideal compressor in the diagrams. Also show and mark the 1000 kPa and 17.5 MPa isobars and the 650°C isotherm in the diagrams.

   (b) Find the enthalpy and entropy at 17.5 MPa by averaging between 15MPa and 20 MPa in B.1.3 for the following temperatures: 550°C, 600°C, and 650°C.

   (c) Find the isentropic efficiency.

   (d) Find the total entropy production.

2. Air is blown into a well insulated turbine at 1227°C and 1 MPa and exits at 100kPa. The isentropic efficiency is 85%. Find the work produced by the turbine and the total entropy generated.

3. Air enters an adiabatic compressor with an isentropic efficiency of 70% at 100 kPa and 293 K, at the rate of 2 kg/s and exits at 473 K. What is the power required to run the compressor and its exit pressure. Use constant specific heats from A.5, not A.7.1. Note: this question is a bit tricky because the exit pressure is not given. Compute the quantities in the order asked, switching to the ideal compressor at the appropriate moment.