EML 3100 Exam 4 **THERMODYNAMICS** **4/28/10 3-5 pm**
Page 1/4 Solutions (dommelen@eng.fsu.edu) series a

DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. Put your answers on the same sheet as the question, Use at least 5 digits in your computations and answers where possible. You must give the units of your answers. You must write clearly. Encircle the right answer number in multiple choice. To correct, erase the wrong circle as well as you can and encircle the corrected answer number twice. Best possible answer for multiple choice. For questions asking a number, putting the clear correct formula(s) below the question might result in partial credit even if the answer is wrong. *Not following those requirements will result in reduced or no credit.*

1. (3%) What would you normally best model as a control mass:

   [✓ (a)] A bone
   (b) A heart
   (c) A vein

2. (3%) If you have saturated vapor in an insulated container and you decrease the pressure reversibly,

   (a) it turns into compressed liquid
   [✓ (b)] it turns into two-phase
   (c) it turns into superheated vapor

3. (3%) Air is heating up at a rate of 2°C/min. Assuming that the air pressure remains constant, it is absorbing heat at a rate of 2.008 kJ/kg-min.

4. (3%) Low velocity liquid R-134a is compressed by a horizontal pump from 100 kPa to 1000 kPa at a rate of 0.2 kg/s. The power needed by the pump is at least 149.25 W.

5. (3%) If 2 m^3 of asphalt cools down from 100°C to the ambient temperature of 20°C, its entropy change is -941.676 kJ/K.

6. (3%) What refrigeration cycle is *possible*:

   (a) $W = 0$, $Q_H = 5$, $Q_L = 5$
   (b) $W = 5$, $Q_H = 0$, $Q_L = 5$
   [✓ (c)] $W = 5$, $Q_H = 5$, $Q_L = 0$

7. (3%) Argon enters a reversible insulated compressor at 100 kPa and 300 K and comes out at 400 K at the same height and velocity that it entered. The work required by the compressor is 52.009 kJ/kg.

8. (3%) A proposed geothermal power generator extracts heat from a reservoir at 27°C and uses cooling water from the local river at 7°C. If the thing is supposed to generate 4 MW of power, it must take in at least 60 MW of heat from the reservoir and will add heat to the local river at a rate of at least 56 MW.

9. (3%) The air pressure on top of Mount Everest is 31.2 kPa. Water boils there at 70 °C.

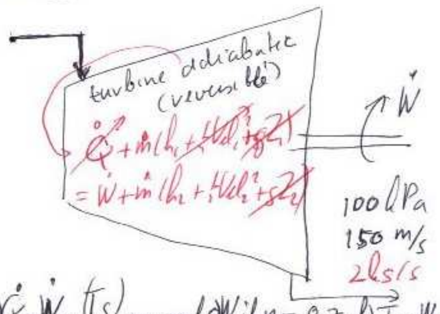
10. (3%) Suppose that it is -10°C outside and 20°C inside your house and you need to add heat to your house at a rate of 3,000 W. Then a resistance heater would need 3,000 W of electricity while an ideal heat pump would need 307 W.

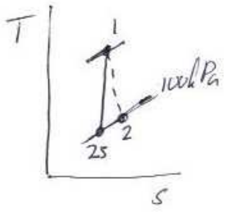
11. (35%) Air at 500 kPa and 1100 K enters an adiabatic turbine at a rate of 2 kg/s with negligible velocity. It exits at 100 kPa with a velocity of 150 m/s.
    - (a) Assuming that the turbine is reversible, find the heat flow into the turbine and the power produced.
    - (b) Repeat, but now using the data in A.5 only.
    - (c) Now assume that the actual turbine is not reversible, as assumed above. If the turbine efficiency is 0.7, then what are the heat flow and power for the actual turbine?
    - (d) Very neatly sketch the processes through the reversible and actual turbines in the Ts diagram. Show also the isobars through the entrance and exit states in the diagram.

Items are not equal credit. Give at least 5 nontrivial correct digits in your answers.

You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use the maximum number of digits in your computations.

Given in black:
Air
500 kPa
2 kg/s
1100 K
Vel ~ 0





Asked a) $\dot Q$, $\dot W_s$, $(Ts)_{proc}$, real $\dot W$ if $\eta_T = 0.7$, b) T_2, W_s if A.5 only.

Solution $\cancel{s_2 - s_1}^{\,0} = s^o_{T_2} - s^o_{T_1} - R \ln \frac{P_2}{P_1} = s^o_{T_2} - 8.24449 \frac{kJ}{kgK} - .287 \frac{kJ}{kgK} \ln \frac{100}{500}$

$s^o_{T_2} = 7.78258 = g$ $\quad g_1 = 7.77044$ $\quad g_2 = 7.80008$

$h_2 = d$ $\quad d_1 = 735.10$ $\quad d_2 = 756.73$

$h_2 = 743.9602$

$\dot W_s = \dot m(h_1 - h_2 - \frac{1}{2}Vel_2^2) = 2 \frac{kg}{s} (1161.18 - 743.9602 - \underbrace{\frac{1}{2}(150)^2 \frac{1}{1000}}_{11.25}) \frac{kJ}{kg}.$

$= \underline{\underline{811.9396 \text{ kW}}}$ $\quad \underline{\underline{\dot Q = 0}}$

If actual turbine has $\eta_T = 0.7$, then $\dot W_{actual} = \underline{\underline{568.36 \text{ kW}}}$

If A.5 only ~~$\dot W_s =$ [illegible]~~ $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ with $n = k = 1.4$

$T_2 = \underline{\underline{694.5235 \text{ K}}}$

$\dot W_s = \dot m(c_p(T_1 - T_2) - \frac{1}{2}Vel_2^2) = 2 \frac{kg}{s} (1.004 \frac{kJ}{kgK}(1100 - 694.52) - \frac{150^2}{2000})$

$= 791.7 \text{ kW}$

④ $\dot Q = 0$
④ find $s^o_{T_2}$
④ 1st law
③ find T_2
② $\dot W_{actual}$

③ read A.5
④ interpolate h
② compul $\dot W$ units!
③ $h_2 - h_1 = c_p(T_2 - T_1)$ or equiv
② sketch

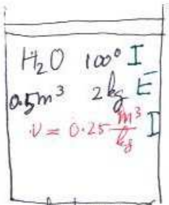
③ Read A.7.1
① $\dot m_1 = \dot m_2$

12. (35%) A piston-cylinder combination contains 2 kg water at 100°C and a volume of 0.5 m^3. It is now isothermally and reversibly compressed to 2,000 kPa at a rate so that the temperature stays constant.
    (a) Construct the initial phase in the Ts diagram, marking all lines and points used to do it with their values. Do not put more info in the diagram than is needed to construct the phase. State the phase.
    (b) The same, but for the final phase and using the Pv diagram.
    (c) Find the heat added to and the work done by the water, with the proper signs.
    (d) If the heat leaks out to a surroundings at 27°C, then what is the generated entropy? So what does the second law say about the possibility and reversibility of the overall process?

Items are not equal credit. Give at least 5 nontrivial correct digits in your answers.

You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use the maximum number of digits in your computations.

Given: in black



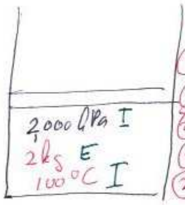
27°C surroundings

$m(s_2-s_1) = \frac{{}_1Q_2}{T_{surr}} + {}_1S_{2gen}$

compressed
isothermal
reversible

$U_2 - U_1 = {}_1Q_2 - {}_1W_2$

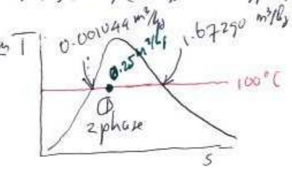
${}_1Q_2 = mT(s_2-s_1)$

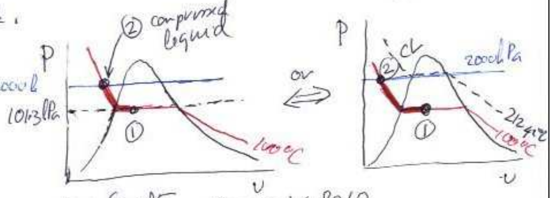


① diagram
② line 1
② find sat
② draw sat
② line 2
② ID

Asked ${}_1Q_2$, ${}_1W_2$ (high accuracy), $(Ts)_1$, $(Pv)_2$, proc, work.

Solution





① $v_1 = v_f + x v_{fg}$ $\quad 0.25 = 0.001044 + x\,1.67185$ $\quad x = \underline{0.148910}$

$u_1 = u_f + x u_{fg} = 418.91 + x\,2087.58 = \underline{729.7728\ kJ/kg}$ $(u_g = 2506.5)$

$s_1 = s_f + x s_{fg} = 1.3060 + x\,6.048 = \underline{2.20741\ kJ/kg\,K}$ $(s_g = 7.3548)$

② $\left[v_2 = 0.001043\ \frac{m^3}{kg}\right]$ $u_2 = \underline{418.36\ \frac{kJ}{kg}}$ $\quad s_2 = \underline{1.3053\ kJ/kg\,K}$

${}_1Q_2 = mT(s_2-s_1) = 2kg\,(100+273.15)K\,(1.3053-2.20741)\frac{kJ}{kg\,K} = \underline{\underline{-673.245\ kJ}}$

$m(u_2-u_1) = {}_1Q_2 - {}_1W_2$ $\quad \underbrace{2kg\,(418.36-729.7726)}_{-622.825}\frac{kJ}{kg} = -673.245\,kJ - {}_1W_2$

${}_1W_2 = \underline{\underline{-50.42005\ kJ}}$

${}_1S_{2gen} = m(s_2-s_1) - \frac{{}_1Q_2}{T_{surr}} = 2kg\,(1.3053-2.20741)\frac{kJ}{kg\,K} + \frac{673.245\ kJ}{300\ K}$

$= 0.439929$ $\quad {}_1S_{2gen} > 0$ so process is possible, not reversible

③ Read B.1.1 ③ sat formulae ① find x_1 ① find u_1, s_1
③ Read B.1.4
③ 2nd law isothermal ② find ${}_1Q_2$ units!
③ 1st law ① $m_1 = m_2$ ① find ${}_1W_2$ units!
③ 2nd law global → comment: ½ ① find ${}_1S_{2gen}$ units!

$u_f = 506.97$
1463.85