EML 3100 Exam 4 **THERMODYNAMICS** **4/25/07 3:00-5:00 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 many digits in your computation. 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%) Which is best described thermodynamically as a control mass, normally speaking:

   [✓ (a)] A gearbox.
   (b) A heat exchanger.
   (c) A tank being drained.

2. (3%) We have saturated vapor in a well insulated piston-cylinder contraption. Now we reduce the pressure as much as possible in a reversible way. What is right:

   (a) Liquid water will not form.
   [✓ (b)] Only some liquid water will form.
   (c) Eventually all water will turn liquid.

3. (3%) The air in a classroom is warming up at a rate of 5°C per hour. The internal energy of the air will be increasing at a rate of 3.59 kJ/kg-h

4. (3%) An oil pump compresses engine oil from 100 kPa to 300 kPa at low velocity and without height changes. The work the oil pump must do is about 0.220 kJ/kg.

5. (3%) When 1 kg of boiling water cools down to the kitchen temperature of 27°C, the generated entropy is about 0.107 kJ/K.

6. (3%) It is -10°C outside and 25°C inside. You use your A/C as a heat pump to heat your house. To obtain 10 kW of heat, even the best A/C will be needing at least 1.174 kW of electricity.

7. (3%) Helium initially at 27°C and 100 kPa is being compressed isentropically to 1 MPa at a rate of 2 kg/s. Assuming kinetic and potential energy changes can be ignored, the compressor power requirement will be 4711 kW.

8. (3%) We have 2 kg of water at 25°C that has an internal energy of 200 kJ. The phase of the water is:

   [✓ (a)] Subcooled liquid.
   (b) Saturated.
   (c) Superheated vapor.

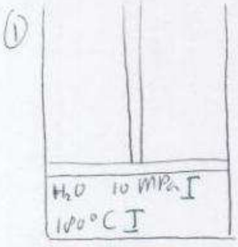
9. (3%) If 2 kW of heat comes out of your resistance heater, which is at a temperature of 327°C and goes into a house at 27°C, the rate of entropy generation is 3.33 W/K.

10. (3%) Your car engine has a thermal efficiency of 25%. If it is producing 100 kW of power, the heat given off to the environment will be 300 kW.

11. (35%) A piston cylinder device contains water at 10 MPa and 180°C. The water is now reversibly expanded to 100 kPa while keeping the temperature constant.

    - Construct both phases in a very neat Ts diagram, marking all lines and points used to do it with their values. Unambiguously number the phases in the diagram. Show the process as a fat line.
    - What is the heat added to the water?
    - What is the work done by the water?

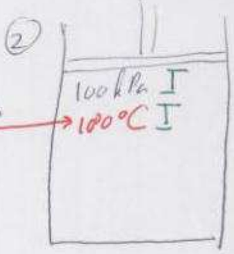
    You must show the derivations and reasoning completely and correctly for full credit. You must give units for your answers. Most accurate procedure only unless stated otherwise.



reversible expansion isothermal $\longrightarrow$

$q_{12} = T(s_2 - s_1)$

$u_2 - u_1 = q_{12} - w_{12}$

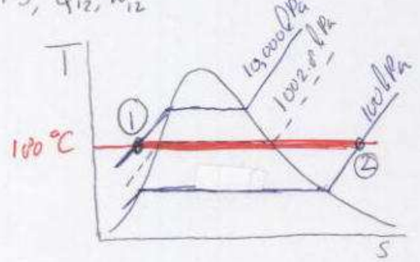


No extensive: use specific

Asked Ts, Q_{12}, W_{12}

Solution

② bubble
③ isobars
③ isotherm
③ sat val
② process



③ read A-7 Table A-7 @ 10 MPa, 180 °C: $u_1 = 756.48 \frac{kJ}{kg}$ $s_1 = 2.1271 \frac{kJ}{kg\,K}$

③ read A-6 Table A-6 @ 0.1 MPa, 180°C interpolated

③ interpolate $\xi = 180\,°C$ $\xi_1 = 150\,°C$ $\xi_2 = 200\,°C$

u $d_1 = 2582.9$ $d_2 = 2658.2$ $u_2 = 2628.08$ kJ/kg

⑤ heat formula s $d_1 = 7.6148$ $d_2 = 7.8356$ $s_2 = 7.74728$ kJ/kg K

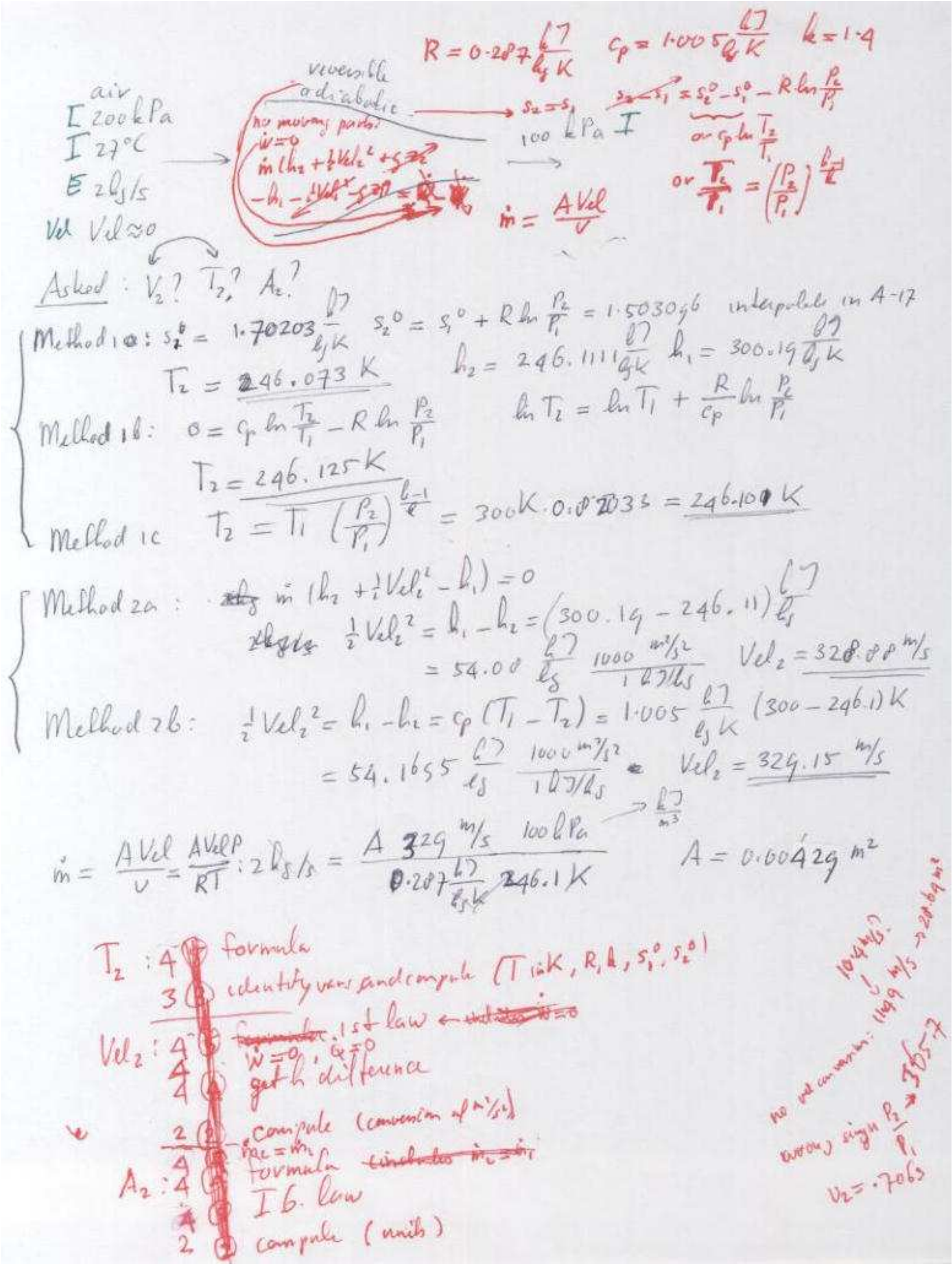
② find q $q_{12} = T(s_2 - s_1) = (180 + 273)\text{K} \, \overbrace{(7.74728 - 2.1271)}^{5.62018} \frac{kJ}{kg\,K} = \underline{\underline{2545.9 \frac{kJ}{kg}}}$

⑤ 1st law $u_2 - u_1 = q_{12} - w_{12}$ $(2628.08 - 756.48)\frac{kJ}{kg} = 2545.9 \frac{kJ}{kg} - w_{12}$

① find w $w_{12} = \underline{\underline{674.34 \frac{kJ}{kg}}}$

12. (35%) Air enters an horizontal adiabatic nozzle at 200 kPa and 27°C at a rate of 2 kg/s with negligible velocity and exits at 100 kPa. If the flow process through the nozzle is assumed to be reversible, what it the exit temperature? What is the exit velocity? What is the exit area of the nozzle?

You must show the derivations and reasoning completely and correctly for full credit. You must give units for your answers. Most accurate procedure only unless stated otherwise.



$R = 0.287 \frac{kJ}{kg\,K}$ $c_p = 1.005 \frac{kJ}{kg\,K}$ $k = 1.4$

air
I 200 kPa
I 27°C
E 2 kg/s
Vel Vel ≈ 0

reversible adiabatic → $s_2 = s_1$

100 kPa I

no moving parts: $\dot W = 0$

$\dot m(h_2 + \frac{1}{2}Vel_2^2 + gz_2 - h_1 - \frac{1}{2}Vel_1^2 - gz_1) = \cancel{\dot Q} - \cancel{\dot W}$

$s_2 - s_1 = \underbrace{s_2^o - s_1^o}_{\text{or } c_p \ln \frac{T_2}{T_1}} - R \ln \frac{P_2}{P_1}$

or $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$

$\dot m = \frac{A\,Vel}{v}$

Asked: V_2? T_2? A_2?

Method 1a: $s_1^o = 1.70203 \frac{kJ}{kg\,K}$ $s_2^o = s_1^o + R \ln \frac{P_2}{P_1} = 1.503046$ interpolate in A-17

$T_2 = 246.073$ K $h_2 = 246.1111 \frac{kJ}{kg\,K}$ $h_1 = 300.19 \frac{kJ}{kg\,K}$

Method 1b: $0 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$ $\ln T_2 = \ln T_1 + \frac{R}{c_p} \ln \frac{P_2}{P_1}$

$T_2 = 246.125$ K

Method 1c $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 300\text{K} \cdot 0.82033 = 246.100$ K

Method 2a: $\dot m(h_2 + \frac{1}{2}Vel_2^2 - h_1) = 0$

$\frac{1}{2}Vel_2^2 = h_1 - h_2 = (300.19 - 246.11) \frac{kJ}{kg}$

$= 54.08 \frac{kJ}{kg} \frac{1000\ m^2/s^2}{1\ kJ/kg}$ $Vel_2 = 328.88$ m/s

Method 2b: $\frac{1}{2}Vel_2^2 = h_1 - h_2 = c_p(T_1 - T_2) = 1.005 \frac{kJ}{kg\,K}(300 - 246.1)$K

$= 54.1655 \frac{kJ}{kg} \frac{1000\ m^2/s^2}{1\ kJ/kg}$ $Vel_2 = 329.15$ m/s

$\dot m = \frac{A\,Vel}{v} = \frac{A\,Vel\,P}{RT} : 2\ kg/s = \frac{A\ 329\ m/s\ 100\ kPa}{0.287 \frac{kJ}{kg\,K}\ 246.1\,K}$ $\to \frac{kJ}{m^3}$ $A = 0.00429\ m^2$

T_2 : 4 formula
3 identify vars and compute (T in K, R, k, s_1^o, s_2^o)
Vel_2 : 4 ~~formula~~ 1st law ← ~~[illegible]~~ $\dot W = 0$
4 $\dot W = 0$, $\dot Q = 0$
4 get h difference
2 compute (conversion of m^2/s^2)
$\dot m_2 = \dot m_1$
4 formula ~~[illegible] $\dot m_2 = \dot m_1$~~
A_2 : 4 IG law
~~4~~
2 compute (units)

10.4 m/s?
1149 m/s → 28.69 m²
no vel conversion:
wrong sign $\frac{P_2}{P_1}$ → 365.7
$v_2 = .7063$