EML 3002C Exam 4 ME TOOLS THERMO 12/11/15 7:30-9:30 am
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 significant 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%) A horizontal reversible pump with entrance and exit pipes of equal diameter uses 3 kW of electricity to compress 2 kg/s of liquid benzene entering at the ambient pressure of 100 kPa. The pressure of the exiting benzene will be ___1418.5___ kPa.

2. (3%) A 2 kg/s flow of steam, in this question to be treated as an ideal gas with constant specific heats, enters an isentropic steam turbine at 2 MPa and exits it at 100 kPa and 400 K. The specific work produced will be ___818.18___ kJ/kg.

3. (3%) A piston-cylinder combination contains 0.5 kg of hot argon kept at 150 kPa by the weighted piston. If the temperature is decreasing at a rate of 0.3°C/s, then the heat that leaks out must be ___78___ W (note units).

4. (3%) The deepest point in the oceans is 11 km below sea level. Assuming the properties of water at standard conditions (25°C), standard atmospheric pressure, and standard gravity, the pressure is at that depth ___107,651___ kPa. (Compare with the yield stress of steel, say 250,000 kPa).

5. (3%) A piston with a diameter of 5 cm is to keep a substance at a pressure of 3 bar. The ambient pressure is 1 bar. The mass of the piston must be 40.044 kg.

6. (3%) If 2 kg of liquid benzene cools down from 350 K to the ambient temperature of 300 K, the heat released by the benzene is 172 kJ, its entropy decreases by 0.53026 kJ/K, and the entropy generated in the complete system is 0.043055 kJ/K.

7. (3%) Assume you have a substance in an adiabatic piston/cylinder combination. Gentle or not so gentle, you push and pull the piston, until a final state at which you feel that the gas pressure on the piston is again the same as the initial pressure. What is the most precise thing that you can say about the final temperature relative to the initial temperature? If you do it gentle, reversibly, the final temperature will be the same. If you do it wildly, the final temperature will be higher or the same.

8. (3%) Using 3 kJ of electric energy, the most heat you could possibly remove from your -13°C freezer in your 20°C kitchen is 23.65 kJ.

9. (3%) Of the below systems, 2 should normally be modeled as a control mass, 1 as a control volume, and 3 as either one, depending on what you are interested in.
   1. An aircraft jet engine.
   2. A Stirling engine.
   3. A water droplet in dry air.

10. (3%) Steam at 1200 kPa and 250°C flows through a pipe with a 3 cm diameter at a rate of 3 kg/s. The flow velocity of the steam is 816.3 m/s.

11. (35%) Water at 100 kPa and 6.13 kJ/kg K enters a horizontal, well insulated, ideal compressor with a velocity of 200 m/s at a rate of 2 kg/s. The compressor compresses it to 8000 kPa and it exits with negligible velocity.
    1. Construct the initial phase in a very neat Pv-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.
    2. Do the same for the final phase, after figuring out the needed information about the final state. Also show the process as a fat line in the second diagram. Also show the specific work graphically in the diagram.
    3. Compute the power requirement of the compressor.
    4. If the actual compressor has an exit temperature of 400°C, what is its efficiency?

    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 at least 5 significant digits in your computations and answers. *Give the source of every number.*

Given: in black

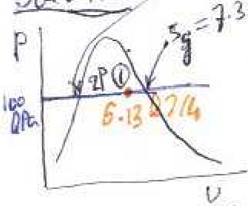
H_2O 100 kPa
6.13 kJ/kg K
200 m/s
2 kg/s

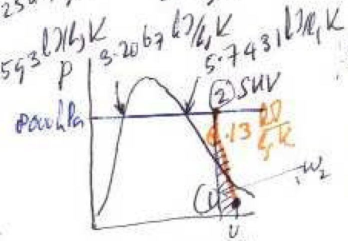
$$\dot Q + \dot m_1 (h_1 + \tfrac{1}{2} Vel_1^2 + g z_1) = \dot W + \dot m_2 (h_2 + \tfrac{1}{2} Vel_2^2 + g z_2)$$

$s_2 = s_1 = 6.13$ kJ/kg K

1 diagram	read B.1.2
1 line 1	2 phase
2 find sat	find x, h_1
1 plot sat	Read B.1.3 h_2
1 line 2 (sat)	$\dot m_1 = \dot m_2$
1 locate	1st law
2 ID	find W while
2 work	find η_c

Solution:





B.1.2 @ 100 kPa

$$\boxed{\begin{aligned} &s_f = 1.3025 \quad s_{fg} = 6.0568 \quad s_g = 7.3593 \ \tfrac{kJ}{kg\,K} \\ &h_f = 417.44 \quad h_{fg} = 2258.02 \quad h_g = 2675.46 \ \tfrac{kJ}{kg} \end{aligned}}$$

$s = s_f + x s_{fg}$ $6.13 = 1.3025 + x\, 6.0568$ $x = \boxed{.79704}$

$h_1 = h_f + x h_{fg} = 2217.17$ kJ/kg

B.1.3 @ 8000 kPa, 6.13 kJ/kg K: $h_2 = 2987.30$ kJ/kg

1st law: $2\,\text{kg/s}\,\Big(\underbrace{2217.17\,\frac{kJ}{kg} + \frac{1}{2}\,200^2\,\frac{m^2}{s^2}\,\frac{1\,kJ/kg}{1000\,m^2/s^2} - 2987.3\,\frac{kJ}{kg}}_{-770.13\,kJ/kg\,+\,20\,kJ/kg\,=\,-750.132}\Big) = \dot W_s = \boxed{-1500.3\ kW}$

+ for required

actual: $h_2 = 3138.28$
$\dot W_{act} = 1802.22$

$\eta_c = \dot W_s / \dot W_{act} = \boxed{0.83247}$

12. (35%) Consider an ideal Otto cycle using standard air. We want to compare a 2006 Miata to a 2016 Miata. We start with the 2006 Miata. Assume that its compression ratio is 11 (rounded up from 10.8). Also assume that the engine has taken in 2 L of air at 26.85°C and 100 kPa at the start of the compression stroke. That makes the total volume of air, including residual air, in the cylinder at that time $2 \times 11/10 = 2.2$ L. To compute the heat added during the combustion, assume that the fuel has 1/12 the mass of the 2 L intake air, and an effective heating value of 22,000 kJ/kg fuel. (Before you complain that Wikipedia says 45,000, this has been reduced by roughly a factor 2 from the actual value to account for combustion efficiency and heat leakage). Ignore the mass of the fuel, except in computing the heat added due to the combustion.

   (a) Show the cycle in both the Pv and Ts diagrams, both very neat and accurate. Label the successive phases from 1 through 4, 1 being the start of the compression stroke (*not* the location of peak pressure and temperature).

   (b) The total mass of air in the cylinder is 0.0025552 kg. The heat added during the combustion is 1,666.7 kJ/kg (rounded to three significant digits this should be 1670 kJ/kg, but 5 significant digits must be computed and used.)

   (c) Fill in the following table for the P_i, T_i, and q_{ij}, $i = 1 \ldots 4$, $j = i + 1$, showing the value of each quantity, the formula used to compute it, and the numbers (or table entries) put in the formula, if any.

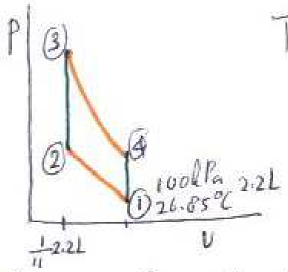
#	P (kPa)	formula numbers	#	T (K)	formula numbers	#	q (kJ/kg)	formula numbers
1	100	given	1	300	26.85°C	1-2	0	adiab
2	2870.4	isen	2	782.85	isen	2-3	1666.7	above
3	11,394	isoch	3	3107.4	isoch heat	3-4	0	adiab
4	396.92	isen	4	1190.8	isen	4-1	638.69	isoch

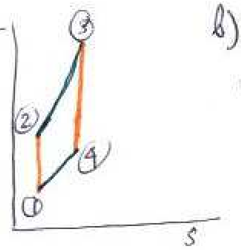
   (d) The specific power produced is 1028 kJ/kgfrom formula net heat in, numbers q23, q41

   (e) The thermal efficiency is 0.61678 from formula definition or formula, numbers

   (f) Now the 2016 Miata is essentially the same, except that its compression ratio has been increased to 13. Without recomputing the above pressures, temperatures, and heat transfers, this would theoretically increase the efficiency to 0.64155. That is a 4 % improvement. Since the same amount of fuel is burned, the power produced should increase by the same percentage, and the specific power even more, as there is less total air. (In real life, the peak horsepower is lower for the 2016 Miata, but the average horsepower is more.)

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 at least 5 significant digits in your computations and answers. *Give the source of every number.*





b) $\underline{A\text{-}5}$ $R = 0.287\,kJ/kg\,K$ $c_v = 0.717\,kJ/kg\,K$ // $k = 1.4$ //

$T_1 = 26.85 + 273.15 = \underline{300\,K}$

intake air mass m_{in}

$P_1 V_{1,in} = m_{in} R T_1$ $\quad 100\,kPa\ 2L \frac{1m^3}{1000L} = m_{in}\,0.287 \cdot 300 \frac{kJ}{kg}$

$m_{in} = 0.0023228\,8kg$ $\quad m_{fuel} = \frac{1}{12} m_{in} = 0.000193573\,kg$

$m_{fuel}\, Q_{HV,fuel} = 4.25861\,kJ$ $\quad m_{tot} = 1.1\, m_{in} = \underline{\underline{0.00255516\,8kg}}$

c) $q_{fuel} = Q_{fuel} / m_{tot} = 4.25861\,kJ / 0.002555168 = \underline{\underline{1666.7\,kJ/kg}}$

$P_1 = 100\,kPa$ given	$T_1 = 300K$ $\quad 26.85 + 273.15$	$q_{12} = 0$ adiabatic
$P_2 = 2870.4\,kPa$ $\quad P_2 = P_1 (v_1/v_2)^k$	$782.85 = T_2$ $\quad T_2 = T_1 (v_1/v_2)^{k-1}$	$q_{23} = 1666.6\,kJ$ see above q_{fuel}
$P_3 = 11{,}393.6\,kPa$ $\quad P_3 = P_2\, T_3/T_2$	$T_3 = 3107.35\,K$ $\quad q_{23} = c_v (T_3 - T_2)$	$q_{34} = 0$
$P_4 = 396.92\,kPa$ $\quad P_4 = P_3 (v_3/v_4)^k$	$T_4 = 1190.78\,K$ $\quad T_4 = T_3 (v_3/v_4)^{k-1}$	$\lvert q_{41} \rvert = 638.69\,kJ$ $\quad \lvert q_{41} \rvert = c_v (T_4 - T_1)$

d) $w = q_{net,in} = 1666.67 - 638.69 = \underline{\underline{1027.97\,kJ/kg}}$ e) $\eta_{th} = \frac{w}{q_{23}} = \underline{\underline{0.61678}} = 1 - \frac{1}{r_v^{k-1}}$

f) $\eta_{th} = 1 - \frac{1}{(13)^{k-1}}$ $\quad k = 1.4$ $\quad \eta_{th} = \underline{0.64155}$ ~~The fuel burned is still the same, but the total mass is $\frac{13}{12}$ instead of $\frac{11}{10}$ larger than min $\rightarrow$ $q_{fuel} = q_{fuel,old} \times \frac{11}{10} / \frac{13}{12} = 1692.3$~~

~~$\rightarrow w = \eta_{th}\, q_{fuel} = 1086.7\,kJ/kg$~~ $\quad \frac{0.64155 - 0.61678}{0.61678} = 0.04016 = 4\%$