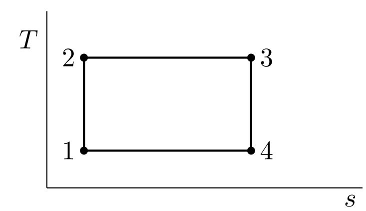
DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. A letter-size formulae sheet, handwritten by you, may be used. Put your answers on the same sheet as the question. Use at least 5 significant digits in your computations and answers where possible. 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. (5%) The work formula for the specific work required by a reversible adiabatic compressor to compress an ideal gas with constant specific heats polytropically is $w = -k(P_2v_2 - P_1v_1)/(1-k)$. Apply this formula to find the power needed to compress 2 kg/s of air with Table A5 specific heats from 300 K to 523 K: 448.01 kW (give 5 digits accurate).

2. (5%) *Neatly and accurately* draw the $T-s$ diagram for the reversible cycle described below. Assume an *ideal gas.* Label each state and state what sort of cycle the entire process is: Carnot Cycle .

   - 1-2 adiabatic pressurization.
   - 2-3 isothermal heating.
   - 3-4 isentropic process.
   - 4-1 polytropic volume reduction with $n = 1$;



3. (5%) Of the following purported refrigeration cycles, case 1 violates the first law, and case 3 violates the second law:
   1. $Q_H = 0$, $Q_L = 7$, $W = 7$.
   2. $Q_H = 7$, $Q_L = 0$, $W = 7$.
   3. $Q_H = 7$, $Q_L = 7$, $W = 0$.

4. (5%) The engineer lost the measured exit data of the adiabatic steam turbine. All the engineer knows is that the steam came out at the ambient pressure of 100 kPa. The measured temperature may have been (a) 300, (b) 400, or (c) 500°C. Also, the intake steam was at 800°C and 1000kPa. What exit temperature(s) would be possible, and if more than one, which would be more likely to be right? (b) 400°C is barely possible, (c) 500°C most likely. .

5. (5%) If 0.5 kg of aluminum at 300°C cools down to the surrounding temperature of 10°C, the heat released is 130.5 kJ and the entropy generated in the entire system is 0.14356 kJ/K.

6. (5%) A pump that pressurizes 0.5 kg/s of liquid R-134a from 100 to 400 kPa will need at least 0.12438 kW of power.

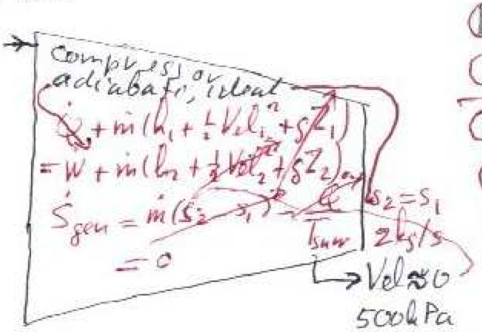
7. (5%) If it is 25°C in the kitchen, then a 0.3 kW refrigerator can remove at most 4.17195 kW of heat from the 5 degree fridge.

8. (32%) A 2kg/s stream of air at 70 kPa and 1.23 m^3/kg enters an ideal adiabatic compressor with a speed of 100 m/s. The air exits the compressor at 500 kPa with negligible velocity.
   1. What is the initial temperature?
   2. Find the power required to run the compressor and the heat that leaks out of it to the 5°C surroundings.
   3. What is the entropy generated in the entire system?
   4. If a corresponding real compressor has an efficiency of 85%, how much power would it require and with what pressure would the air exit?

   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 block

air 2kg/s
70 kPa
1.23 m³/kg
100 m/s



Asked

Solution: $Pv = RT$ 70 kPa 1.23 m³/kg $= 0.287 \frac{kJ}{kg\,K} T_1$ $T_1 = 300\ K$

Table A.7.1 $s^0_{T_1} = 6.86926\ \frac{kJ}{kg\,K}$, $h_1 = 300.47\ kJ/kg$ ($u_1 = 214.36\ kJ/kg$)

$0 = s_2 - s_1 = s^0_{T_2} - s^0_{T_1} - R\ln P_2/P_1$

$s^0_{T_2} = s^0_{T_1} + R\ln P_2/P_1 = 6.86926 \frac{kJ}{kg\,K} + 0.287\frac{kJ}{kg\,K}\ln\left(\frac{500}{70}\right) = 7.43353\ \frac{kJ}{kg\,K} = g$

$d = h_2$ $g_1 = 7.42736$ $g_2 = 7.46642$ $d_1 = 523.98$ $d_2 = 544.69$

$h_2 = d = d_1 + \frac{g - g_1}{g_2 - g_1}(d_2 - d_1) = 527.25\ kJ/kg = h_2$ ($T_2 = 523.16$)

1st law:

$\dot W = \dot m(h_1 + \frac{1}{2}Vel_1^2 - h_2) = 2\ kg/s\left(300.47\frac{kJ}{kg} - 527.25\frac{kJ}{kg} + \frac{1}{2}100^2\frac{m^2}{s^2}\frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$

$= -443.56\ kW$ $\dot W_{in} = 443.56\ kW$ $\dot Q = 0$

2nd law $\dot S_{gen} = 0$

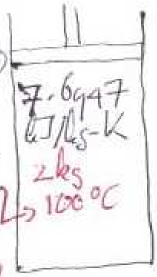
Real compressor: $\eta_c = \frac{w_s}{w} \rightarrow \dot W = \frac{\dot W_s}{\eta_c} = \frac{443.56\ kW}{0.85} = 521.84 = \dot W_{in,real}$

9. (33%) A piston-cylinder is immersed in a pot of boiling water that keeps it at 100°C. The piston-cylinder contains 2 kg of water at 100°C and 5 kJ/kg-K. The water inside the cylinder is then expanded slowly, reversibly, to 7.6947 kJ/kg-K.
   1. Construct both the initial and final phases together in a *single* very neat Ts diagram, and also in a *single* very neat Pv-diagram. Mark all lines and points used to do it with their values. Do not put more info in the diagrams than is needed to construct the phases. State each phase. Show the process line between the phases as a thick line and indicate the specific work and heat graphically.
   2. What are the initial and final pressures?
   3. Find the work that must be done on the water in the cylinder to expand it, and the heat added to the water.
   4. Derive the net entropy generated in the entire system; the water inside the cylinder and the boiling water in the pot.

   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.*

(9) Given: In black:

reversible →
kept at 100°C
${}_1Q_2 = T(S_2 - S_1)$



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

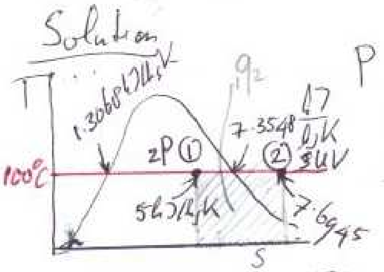
${}_1S_{2gen} = S_2 - S_1 - \frac{{}_1Q_2}{T_{surr}}$

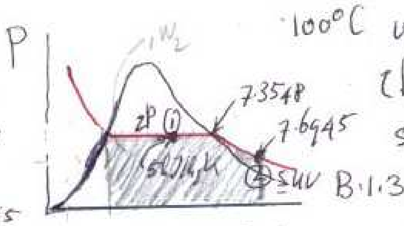
(1) diagram
(1) line 1
(2) find sat right lowest only
(2) plot sat
(2) line 2 vel
(2) ID
(1) heat
(1) work
12

(1) P_1 other B 1.1
(2) P_2, u_2, s_2 B.1.3
(2) 2P formula
(1) find x_1
(1) find u_1
8

(3) ${}_1Q_2 = T(S_2 - S_1)$
(1) find ${}_1Q_2$, units
(3) 1st law
(1) find ${}_1W_2$, units
(2) 2nd law
(1) show 0
(1) $m_2 = m_1$
(1) $T_2 = T_1$
13

Solution





100°C $P_s = 101.3$ kPa $= P_1$

$u_f = 418.91$ $u_{fg} = 2087.58$ $u_g = 2506.50$ kJ/kg

$h_f = 419.02$ $h_{fg} = 2257.03$ $h_g = 2676.05$

$s_f = 1.3068$ $s_{fg} = 6.0480$ $s_g = 7.3548$ kJ/kgK

B.1.3 @ 100°C, 7.6947 kJ/kgK: $P_2 = 50$ kPa, $u_2 = 2511.61$ kJ/kg ($h_2 = 2682.52$)

2nd law #1: ${}_1Q_2 = T(S_2 - S_1) = T_m(S_2 - S_1)$ kJ/kgK $=$ 2,011.1 kJ $= {}_1Q_2$

$= (100 + 273.15)$ K 2kg $(7.6947 - 5)$ kJ/kgK

$x_1 = \frac{5 - 1.3068}{7.3548 - 1.3068} = \frac{3.6932}{6.048} = 0.61065 = x_1$, $u_1 = u_f + x u_{fg} = 1693.69$ kJ/kg $= u_1$

1st law: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$, ${}_1W_2 = 2011.1$ kJ/kg $-$ 2kg $(2511.61 - 1693.69)$ kJ/kg

${}_1W_2 = 375.25$ kJ

2nd law: ${}_1S_{2gen} = S_2 - S_1 - \frac{{}_1Q_2}{T_{surr}} = \frac{{}_1Q_2}{T} - \frac{{}_1Q_2}{T_{surr}} = 0 = {}_1S_{2gen}$