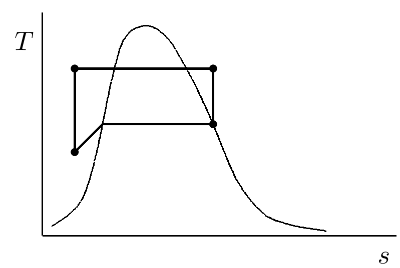
DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. Put your answers on the same sheet as the question, Use at least 5 digits in your computations and answers where possible. You must give the units of your answers. You must write clearly. Encircle 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. (5%) Saturated steam enters an adiabatic compressor and is compressed to saturated liquid.
   (a) The process is irreversible.
   (b) The process is reversible.
   ((c)) The process is not possible.

2. (5%) Sulfur trioxide is compressed from 100 kPa and 300 K to 400 K in a reversible adiabatic process. Assuming that the specific heats remain constant, the final pressure will be 578.604 kPa.

3. (5%) *Neatly* draw the $T-s$ diagram for the reversible cycle described below. Label the states.
   - 1-2 isobaric heating from compressed liquid to saturated vapor.
   - 2-3 reversible adiabatic compression to superheated vapor.
   - 3-4 isothermal cooling.
   - 4-1 isentropic temperature reduction.



4. (5%) Which of the following heat engines is not possible:
   (a) $W = 0$, $Q_L = 0$, $Q_H = 0$
   ((b)) $W = 0$, $Q_L = 0$, $Q_H = 1$
   (c) $W = 0$, $Q_L = 1$, $Q_H = 1$

5. (5%) A reversible pump is used to increase the pressure of liquid ammonia from 100 kPa to 800 kPa. Ignoring potential and kinetic energy changes, the specific work required will be 1.15894 kJ/kg.

6. (5%) As 2 m^3 of asphalt is heated by the sun from 26.85°C to 126.85°C, its entropy increases by 1122.19 kJ/K.

7. (5%) A freezer must remove 30 kJ of heat from its -8°C interior. It is 25°C in the kitchen. The electricity required to do this is at least 3.73585 kJ.

8. (33%) A piston-cylinder combination contains 3 kg of superheated water vapor at 400 kPa and 200°C. The water is now isothermally compressed until the entropy becomes 5 kJ/kg-K. The process is reversible.

   (a) Construct the final phase in a very neat Ts-diagram. Mark all lines and points used to do it with their values. State the phase. Do not put more info in the diagram than is needed to construct the phases. Show the process as a fat line in the diagram.

   (b) Find the heat that leaks out of the water and the work done in the compression.

   (c) If the heat ends up in the environment at 25°C, then what is the entropy generated in the complete process?

   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.

Given: in black

① SUV H_2O, 3 kg, 400 kPa, 200°C — 25° surroundings, reversibly, isothermally compressed — ② $s = 5$ kJ/kg K, 3 kg, 200°C

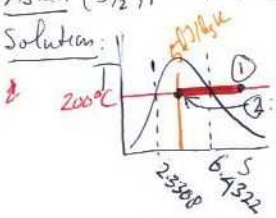
$U_2 - U_1 = {}_1Q_2 - {}_1W_2$

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

~~$m_2 = m_1$, $T_2 = T_1$, heat formula, 1st law, 2nd law, Fink~~ ~~read B.1.3, read B.1.1, 2 phase formula, find x_2, find u_2, ${}_1Q_2$, ${}_1W_2$, ${}_1S_{2gen}$~~

Asked $(Ts)_2$, proc, $-{}_1Q_2$, $-{}_1W_2$, ${}_1S_{2gen}$

Solution:



B.1.3 @ 400 kPa, 200°C $u_1 = 2646.83$ kJ/kg $s_1 = 7.1706$ kJ/kg K

B.1.1 @ 200°C $s_2 = s_f + x s_{fg}$ 5 kJ/kg K $= (2.3308 + x\,4.1014)$ kJ/kg K

$x_2 = 0.650802$ $u_2 = u_f + x u_{fg} = (850.64 + x\,1744.66)$ kJ/kg

$u_2 = 1986.068$

${}_1Q_2 = mT(s_2 - s_1) = 3\text{ kg}\; 473.15\text{ K}\,(5 - 7.1706)\,\frac{\text{kJ}}{\text{kg K}} = -3081.058\text{ kJ}$ (3000.00)

${}_1W_2 = U_1 - U_2 + {}_1Q_2 = m(u_1 - u_2) + {}_1Q_2 = 7940.49 - 5958.21 + {}_1Q_2 = -1097.797\text{ kJ}$ (1982.28)

${}_1S_{2gen} = m(s_2 - s_1) - \frac{{}_1Q_2}{T_{surr}} = (15 - 21.5118)\,\frac{\text{kJ}}{\text{K}} + \frac{3081.058\text{ kJ}}{298.15\text{ K}} = 3.8188\,\frac{\text{kJ}}{\text{K}}$ (3.824)

(-6.5118; 10.33064)

① diagram ① line 1 ① find sat, no line ① plot sat ① line 2, val. sat ① ID ① proc

① $m_2 = m_1$ ① $T_2 = T_1$ ② units on T ② Read B.1.3 ① Read B.1.1 ④ 2 phase formula ① find x

④ heat formula ① find ${}_1Q_2$ units out — 5

④ first law ① find ${}_1W_2$, units ③ 2nd law ① find ${}_1S_{2gen}$, units — 9

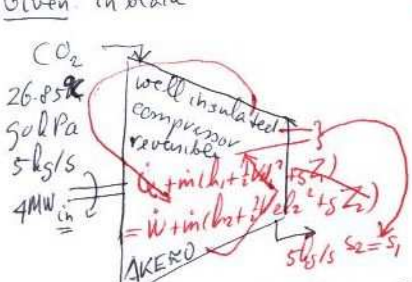
9. (32%) Carbon dioxide enters a well insulated compressor at a rate of 5 kg/s at 26.85°C and 90 kPa. The reversible compressor uses 4 MW of power. Kinetic energy changes across the compressor can be ignored.

   (a) Find the final temperature and then the pressure. Show all numbers that you put in the formula for the pressure, or no credit.

   (b) If you assume that the specific heats of carbon dioxide are constant at their 25°C value, what would you conclude about the final temperature instead based on the appropriate work formulae?

   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.

Given: in black



(1) $\dot{m}_1 = \dot{m}_2$
(2) Read A8
(1) Read A5 [illegible]
(3) Interpolate
(1) °C → K
8

(4) 1st law
(1) $\dot{W} = -\dot{W}_{in}$
(2) $\dot{Q} = 0$
[illegible]
(2) know interpolate
(1) compute T_2 units
10

(4) $s_2 = s_1$
(3) enthalpy formula
(1) compute P_2 units
(2) work formula
(3) $Pv = RT$
[illegible]
14

Asked: [illegible], T_2, P_2. If CSH, T_2 from work = ?

Solution: A-8 CO_2 @ 26.85°C = 300 K: $h_1 = 214.38\ \frac{kJ}{kg}$ $s^0_{T_1} = 4.8631\ \frac{kJ}{kgK}$

1st law $5\frac{kg}{s}\,214.38\frac{kJ}{kg} = -4000\frac{kJ}{s} + 5\frac{kg}{s}h_2$ $h_2 = 1014.38\ \frac{kJ}{kg}$

1071.9 4000 kJ/s

$\frac{g - g_1}{g_2 - g_1} = .342529$

$g = 1014.38$ $g_1 = 971.67$ $g_2 = 1096.36$ kJ/kg $T_2 = 1034.25$ K

$d = T$ $d_1 = 1000$ K $d_2 = 1100$ K

$d = s^0_T$ $d_1 = 6.119$ $d_2 = 6.2379$ kJ/kgK $s^0_{T_2} = 6.15972$ kJ/kgK

$s_2 - s_1 = 0 = s^0_{T_2} - s^0_{T_1} - R\ln\frac{P_2}{P_1}$ $0 = (6.15972 - 4.8631)\frac{kJ}{kgK} - 0.1889\frac{kJ}{kgK}\ln\frac{P_2}{P_1}$

1.29662

$\ln\frac{P_2}{P_1} = 6.864$ $P_2 = P_1 e^{6.864} = 86\,155$ kPa $= 86.155$ MPa

$-\frac{4000\,kW}{\dot{m}} = \frac{n(P_2v_2 - P_1v_1)}{1-n} \underset{n=k}{=} \frac{kR(T_2 - T_1)}{1-k} = \frac{1.289 \cdot 0.1889\frac{kJ}{kgK}(T_2 - 300)K}{1 - 1.289}$

$T_2 = 1249.52$ K