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.*

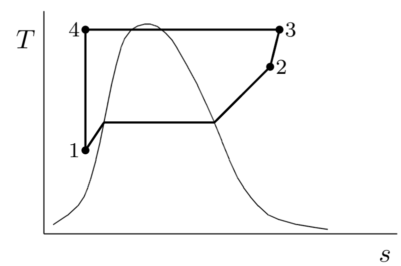
1. (5%) The entropy of saturated water at 370 °C and 0.003 $m^3$/kg equals <u>4.3099</u> kJ/kg K.

2. (5%) When a plastic bottle with 0.3 kg of spring water at 25°C is put in a 5°C fridge, it will release <u>25.08</u> kJ of heat and the entropy generated in the complete fridge will be <u>0.0030942</u> kJ/K.

3. (5%) To remove 30 kJ of heat from a 5°C fridge in a 25°C, kitchen requires at least <u>2.1571</u> kJ of electricity.

4. (5%) *Neatly* draw the $T - s$ diagram for the reversible cycle described below. Label the states.

   - 1-2 Isobaric from compressed liquid to superheated vapor.
   - 2-3 isochoric heating
   - 3-4 isothermal cooling
   - 4-1 isentropic expansion.




5. (5%) To see whether it is worthwhile to improve the oil pump in a car, assume it needs to pressurize 0.3 kg/s of engine oil from 100 kPa to 500 kPa. Then it needs to take at least <u>135.59</u> W of power from the crankshaft.

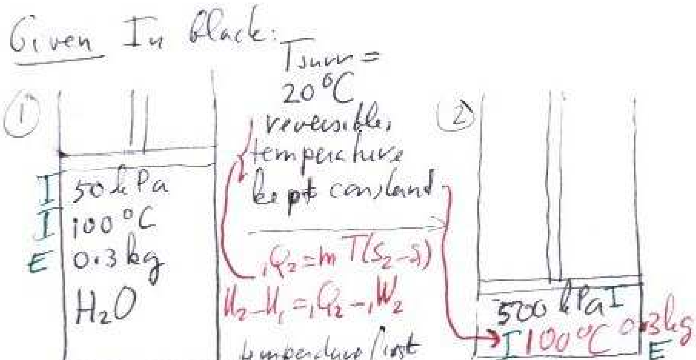
6. (5%) Of the following purported heat pumps, case <u>3</u> violates the first law, and case <u>1</u> violates the second law:
   1. $W = 0$, $Q_L = 1$, $Q_H = 1$.
   2. $Q_L = 0$, $Q_H = 1$, $W = 1$.
   3. $Q_H = 0$, $W = 1$, $Q_L = 1$.

7. (5%) An adiabatic turbine is designed to take in 2 kg/s of steam at 4,000 kPa and 1300°C and expand it to saturated vapor at 20°C. How would you rank this design? <u>impossible</u>.

8. (33%) A piston-cylinder contains 0.3 kg of water at 100°C and 50 kPa. Heat leaks out to the cooler surroundings at 20°C, but the water is compressed by the piston to keep its temperature at 100°C. This continues until the pressure in the water reaches 500 kPa. The process within the cylinder is reversible.
   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. Do temperature first. 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. Find the work done by the water on the piston and the heat that leaks out to the surroundings.
   3. Find the net entropy generated in the entire system.

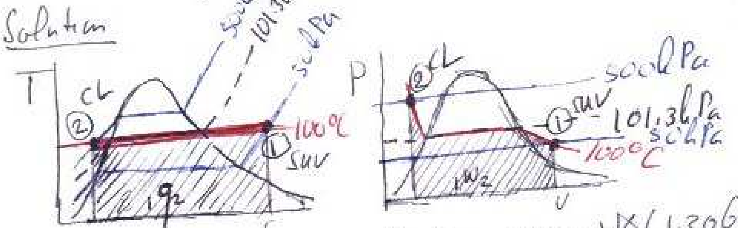
   You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*

Given In black:




Asked $(Ts)_{1,2,q}$, $(Pv)_{1,2,w}$, ${}_1Q_2$, ${}_1W_2$, ${}_1S_{2gen}$

Solution




B.1.3 @ 50 kPa, 100°C
$u_1 = 2511.61\ \frac{kJ}{kg}$, $s_1 = 7.6947\ \frac{kJ}{kgK}$

B.1.4 @ 500 kPa, 100°C
$u_2 = 418.8\ \frac{kJ}{kg}$, $s_2 = 1.3065\ \frac{kJ}{kgK}$

$${}_1Q_2 = mT(s_2 - s_1) = 0.3\,kg\,(100 + 273.15)\,K\,(1.3065 - 7.6947)\,\frac{kJ}{kgK} = \boxed{-715.13\,kJ} = {}_1Q_2$$

(−6.3882)

$${}_1W_2 = {}_1Q_2 + U_1 - U_2 = -715.13\,kJ + 0.3\,kg\,(2511.61 - 418.8)\,\frac{kJ}{kg} = \boxed{-87.284\,kJ} = {}_1W_2$$

(−2383.8; 2092.81; 627.84)

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

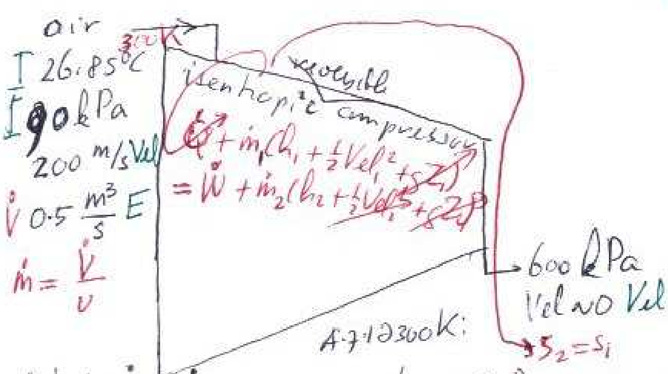
$$= 0.3\,kg\,(1.3065 - 7.6947)\,\frac{kJ}{kgK} + \frac{715.13\,kJ}{273.15 + 20\,K} = \boxed{0.52300\,\frac{kJ}{K}} = {}_1S_{2gen}$$

9. (32%) Air at 90 kPa and 26.85°C enters an ideal adiabatic compressor with a speed of 200 m/s at a rate of 0.5 $m^3/s$. The compressor compresses the air to 600 kPa and it leaves with negligible velocity.
   1. Find the heat released by the compressor and the power required to run it.
   2. If a real adiabatic compressor compressing the same incoming air to 600 kPa has an efficiency of 80%, find the power required to run it.

   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:

R




A.7.1 @ 300 K:

Asked: $\dot Q$, $\dot W_{in}$

Solution: $s_2 - s_1 = s_{T_2} - s_{T_1} - R \ln \frac{P_2}{P_1} \Rightarrow s_{T_2} = 6.86926 \frac{kJ}{kg\,K} + 0.287 \frac{kJ}{kg\,K} \ln \frac{600}{90} = 7.41373 \frac{kJ}{kg\,K} = s^o_{T_2}$ (A5 air; 6.6667; .54447; 1.8971)

A.7.1 interpolated $s = 7.41373$, $d = h$: $s_1 = 7.38692$, $s_2 = 7.42736$, $d_1 = 503.36$, $d_2 = 523.98$; $d = d_1 + \frac{s - s_1}{s_2 - s_1}(d_2 - d_1)$ (13.672; .66304; 20.62)

$h_2 = 517.02$ kJ/kg

$P_1 v_1 = RT_1$ 90 kPa $v_1 = 0.287 \frac{kJ}{kg\,K}$ 300 K

$v_1 = 0.95667 \frac{m^3}{kg}$ $\dot m = 0.5 \frac{m^3}{s} / 0.95667 \frac{m^3}{kg} = .52265$ kg/s $= \dot m = \dot m_1 = \dot m_2$

$\dot W = \dot m(h_1 - h_2 + \frac{1}{2}Vel_1^2) = 0.52265$ kg/s $(300.47 \frac{kJ}{kg} - 517.03 \frac{kJ}{kg} + \frac{1}{2} 200^2 \frac{m^2}{s^2} \frac{1\,kJ/kg}{1000\,m^2/s^2}) =$ (−216.56; 20)

$= 0.52265$ kg/s $(-196.56) \frac{kJ}{kg} = -102.73$ kW $= \dot W$  $Q = 0$  $\dot W_{in} = 102.73$ kW

$\dot W_{in,real} = \frac{102.73\text{ kW}}{0.8} = 128.41$ kW

$s_2 = s_1$ 0.8 1st law