Quiz 6 Thermo Solution and Marking Guide

Name: Solutions Section: UBC ID:

1	/12
2	/13
3	/10

1. (12 marks) A steam power plant operates on an ideal Rankine cycle between a boiler pressure of 2 MPa and a condenser pressure of 0.05 MPa. Recall that the steam leaving the isentropic turbine is saturated vapor ($x_3 = 1$), and that leaving the condenser we have ($x_4 = 0$).

   (a) (6 marks) Sketch the complete cycle on the attached T-s diagram, number states as indicated above 1,2,3,4 with 2 being the state entering the turbine.

   (b) (6 marks) Find the thermal efficiency w/q_{boiler}. Complete the table below as you work through this problem.

State	In to:	T (Celsius)	Pressure (bar)	Enthalpy (kJ/kg)	Entropy (kJ/kg/K)
1	boiler	80	20	352	1.1
2	turbine	550	20	3590	7.5
3	condenser	80	0.5	2650	7.5
4	pump	80	0.5	350	1.1

$w_T = h_2 - h_3 = 940 \frac{kJ}{kg}$

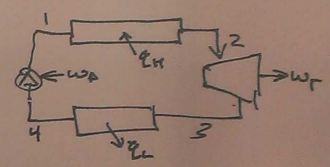
$q_L = h_3 - h_4 = 2300$ kJ/kg

$w_p \sim v(P_1 - P_4) = .001(2000\text{ kPa} - 50\text{ kPa})$
$= 1.95$ kJ/kg

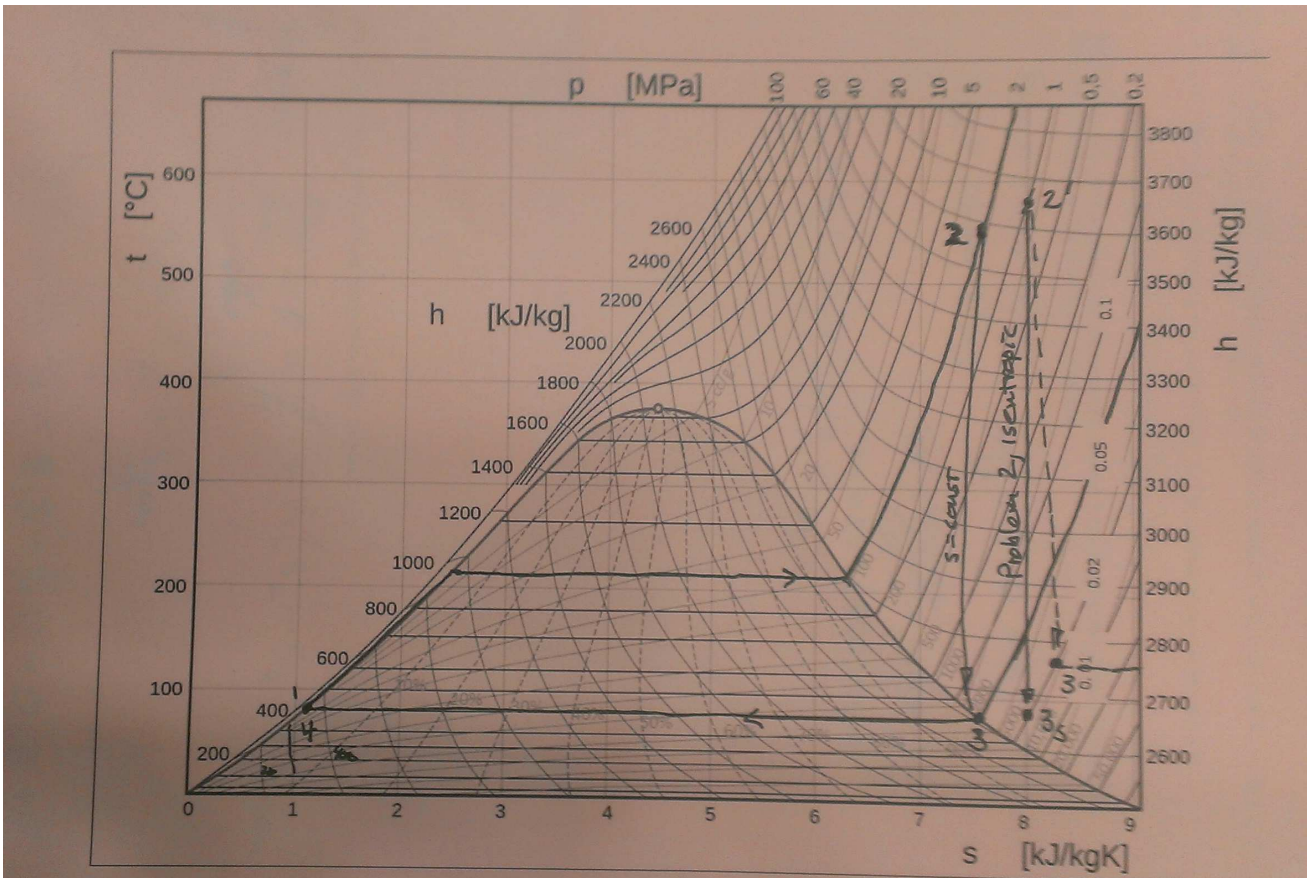
$h_1 = h_4 + w_p = 350 + 1.95 = 352$ kJ/kg

$q_H = h_2 - h_1 = 3238$ kJ/kg

$\eta = \frac{w_T - w_p}{q_H} = 0.29$



It would be ok to use tables for properties, but a little more work. Your efficiency should probably be in the rante 0.27-0.3 given property reading errors. The pump work will have a very small effect on the final result, but 1 mark off if this is neglected without specifically neglecting it because you know it is small.



6 marks for the problem 1 diagram, key features

- 4 processes with the right shape, vertical, horizontal as needed
- 2 marks for locating all 4 states accurately.

A common sleepyhead error would be to mix up MPa and bar. This would propagate errors all the way through, but if methods are correct, take off 3 points only.

2. (13 marks) A steam power plant operates on an Rankine cycle between a boiler pressure of $P_{1'} = P_{2'} = 1$ MPa and a condenser pressure of $P_{4'} = P_{3'} = 0.02$ MPa.

(a) (5 marks) The turbine inlet entropy is $s_{2'} = 8$ kJ/kg/K. The turbine isentropic efficiency is

$$\eta = 0.9 = \frac{w_T}{w_{T_s}}$$

Find the specific work produced by the isentropic turbine (w_{T_s})and by the actual turbine (w_T). Show the processes on the attached T-s diagram.

$h_{2'} = 3650$ kJ/kg

$h_{3s} = 2660$ kJ/kg

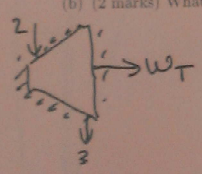
$w_{T_s} = 990 = h_{2'} - h_{3s}$

$\cancel{w_T = (990)(0.9) = 1000 \frac{kJ}{kg}}$

$w_T = 0.9(990) = 891$

$h_3 = h_{2'} - w_T = 2759$ kJ/kg

(b) (2 marks) What is the entropy generation in the turbine?



$$\frac{dS_{cv}}{dt} = \underset{SSSF}{0} = \underset{0}{\cancel{\frac{\dot{Q}}{T}}} + \dot{m}(s_{2'} - s_3) + \dot{S}_{gen}$$

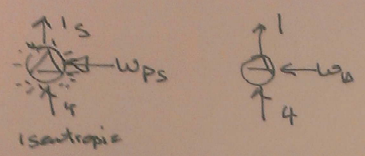
$$s_3 = s_{2'} + \frac{\dot{S}_{gen}}{\dot{m}}$$

$$\frac{\dot{S}_{gen}}{\dot{m}} = s_3 - s_{2'} = 8.3 - 8.0 = 0.3 \frac{kJ}{kg\text{-}K}$$

(c) (3 marks) The entrance to the pump is saturated liquid ($P_4 = 0.02$ MPa, $x_4 = 0$) and the pump isentropic efficiency is

$$\eta = 0.7 = \frac{w_{ps}}{w_p}$$

Find the specific work w_p required by the pump.

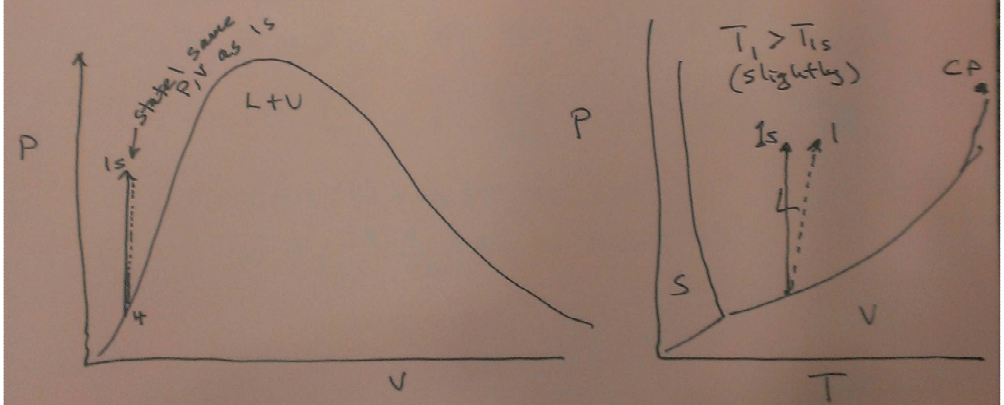


$w_{ps} = v\Delta P$

$= (.001)(1000\,kPa - 20\,kPa) = .98\ \frac{kJ}{kg}$

$w_p = \frac{.98}{.7} = 1.4\ kJ/kg$

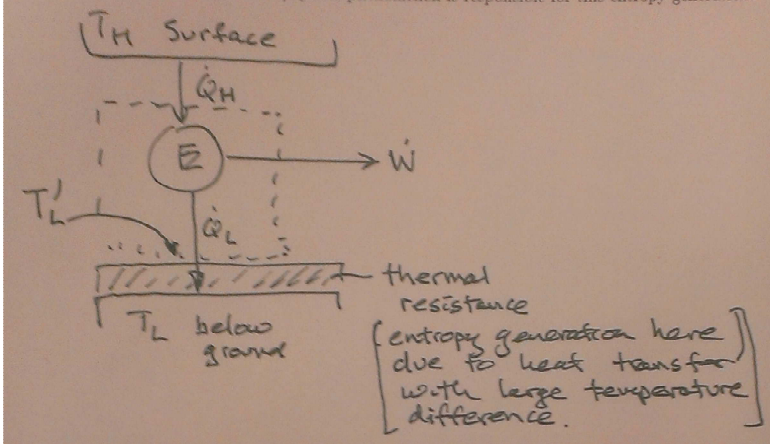
(d) (3 marks) Sketch the pump processes (real and isentropic) on **P-v and P-T diagrams**. Be sure to show the liquid/vapor boundaries on your sketches.



Note that the real and isentropic processes look the same on the P-v diagram, but there is a slight difference on the P-T diagram. On T-s (not requested, but good if you put it there), T and s both increase slightly through the real pump. Practically, these changes are not visible on your T-S diagram because the temperature change would be a fraction of a degree.

3. (10 marks) We will power a robotic probe on Mercury with a heat engine that utilizes the large temperature difference between daytime surface ($T_H = 700K$) and the ground under surface of the planet ($T_L = 400$ K). We will have a very expensive, frictionless Stirling engine, but there is heat transfer resistance through the ground so that the lower temperature for our engine (T_L') is higher than T_L by amount determined by the relation $\dot{Q} = 8(T_L' - T_L)$ [kW].

(a) (5 marks) Make a sketch of the problem and indicate clearly where entropy generation must be occurring. What physical phenomenon is responsible for this entropy generation?



(b) (5 marks) What is the daytime work [kW] that we would get if the heat power rejected to the ground (subsurface) is 80 kW?

$$T_L' = \frac{\dot{Q}}{8} + T_L = \frac{80\text{ kW}}{8} + 400 = 410\text{ K}$$

$$\eta = 1 - \frac{T_L'}{T_H} = 1 - \frac{410}{700} = 0.414 = \frac{\dot{W}}{\dot{W} + \dot{Q}_L}$$

$$0.414(\dot{W} + \dot{Q}_L) = \dot{W}$$

$$\dot{W} = \left(\frac{.414}{1 - .414}\right) 80 = 56.5\text{ kW}$$

There are probably 2 ways to go astray:

1) use the wrong temperature in the Carnot efficiency

2) not realize that QL is 80 kW, but instead think this is QH.