Thermodynamics, MECH2010 Fall 2019, Test 2a 2019/11/12

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Name Chinese________________ Name, Pinyin _________________Student number _Soln_______

Name, English________________

1	2	3	4	5	6	7	Total
20	15	25	25	15			100

Sign your name

I, _________________________, will/did not cheat/copy any portion of this test.

Estimate your score. If it's within +/- 2 points, you get one extra point ______________

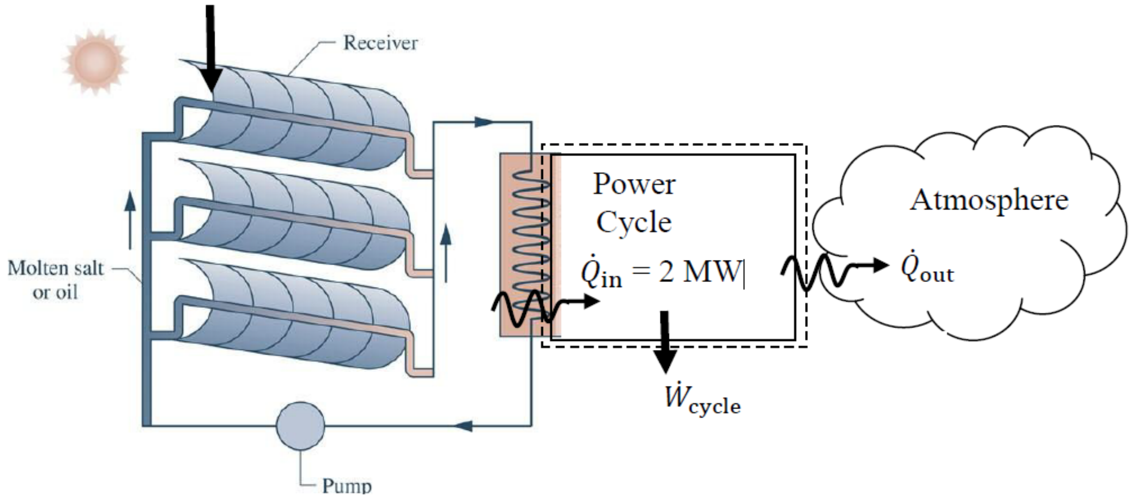
1) A concentrating solar collector system provides energy by heat transfer to a power cycle at a rate of 2 *MW*. The power cycle thermal efficiency is 36%. The air temperature is 27 °C, the molten salt in the heat exchanger is ~800 °C.

a) (4) Determine the power developed by the cycle, in *MW*

b) (6) What is the theoretical max η for the cycle?

c) (4) What is the change in entropy rate, $\Delta\dot{S}$, for the cycle in kW/k ?

d) (6) What is the rate of entropy generation, $\dot{\sigma}$, for the cycle in kW/k?



a) $\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_{in}}$ +2 , $\dot{W}_{cycle} = 0.36(2\text{ MW}) = \boxed{0.72 \text{ MW}}$

b) $\eta_{max} = 1 - \frac{T_C}{T_H}$ +3 $= 1 - \frac{(27+273)}{(800+273)}$ +2 $= 0.72$ $\boxed{72\%}$

c) $\Delta\dot{S}_{cycle} = \boxed{0}$

d) $\Delta\dot{S} = \oint \frac{\dot{Q}}{T} + \dot{\sigma}$ +2

$\dot{\sigma} = -\oint \frac{\dot{Q}}{T} = -\left(\frac{\dot{Q}_{in}}{T_{in}} - \frac{\dot{Q}_{out}}{T_{out}}\right)$

$\dot{W} = \dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out}$

$\dot{Q}_{out} = \dot{Q}_{in} - \dot{W} = (2-0.72)$ +2

$= 1.28 \text{ MW}$

$= -\left(\frac{2}{1073} - \frac{1.28}{300}\right) = 0.00274 \frac{\text{MW}}{\text{K}}$ +1

$= \boxed{2.40 \frac{\text{KW}}{\text{K}}}$

2) An electric in-line water heater is installed in the JCI washroom. For water flowing at a rate of 1 liter/min,
the heater can heat 15 °C water to 30 °C. What is the power input of the heater? Assume pipe diameter = 1 cm before and after the heater

1 liter = 0.001 m^3,

$$\dot{m} = \rho V A = 1000 \frac{kg}{m^3} \frac{0.001\ m^3}{min} \frac{1\ min}{60\ s}$$

$$= 0.0167\ kg/s$$

+3

assume insulated

S.S.

$$\cancel{\frac{\Delta E}{\Delta t}} = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \dot{m}\left[\left(h + \cancel{\frac{V^2}{2}} + \cancel{gz}\right)_1 - \left(h + \cancel{\frac{V^2}{2}} + \cancel{gz}\right)_2\right]$$

+5

$$\dot{W}_{cv} = \dot{m}(h_1 - h_2)$$

$$h_1 = 62.99\ kJ/kg$$

+5 $$h_2 = 125.8\ kJ/kg$$

$$\dot{W}_{cv} = -1.05\ \frac{kJ}{s}$$

$$= \boxed{-1.05\ kW}$$

or

$$\boxed{\text{power input} = 1.05\ kW}$$

→ can we assume $V_1 = V_2$?

$$\dot{m}_1 = \dot{m}_2 \Rightarrow (\rho V A)_1 = (\rho V A)_2$$

$$A_1 = A_2 \qquad \frac{V}{v}\Big|_1 = \frac{V}{v}\Big|_2$$

$$v_1 @ 15°C = 1.0009 \times 10^{-3}\ m^3/kg$$

$$v_2 @ 30°C = 1.0043 \times 10^{-3}\ m^3/kg$$

$$V_2 = V_1 \frac{v_2}{v_1} = 0.994\ V_1$$ ← less than 1% diff!

in your fluid dynamics class, you'll assume all liquid as incompressible (ie. ρ = const)

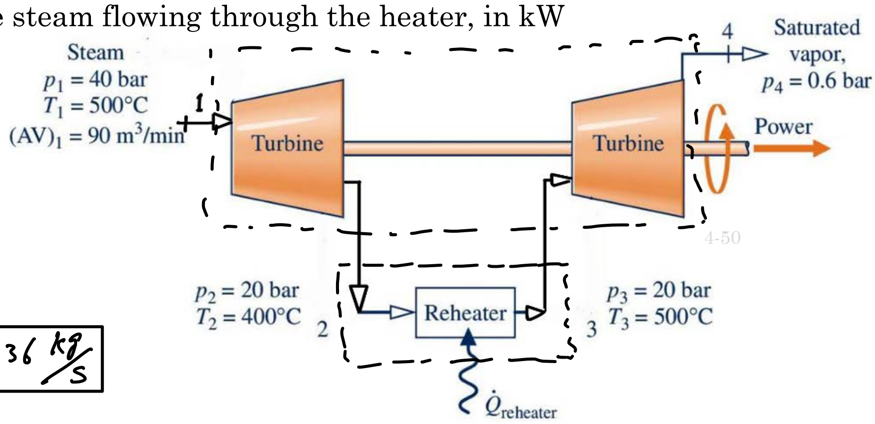
Also, Δh is in terms of kJ/kg $\Delta \frac{V^2}{2} + \Delta g z$ is in J/kg!

3) Steam enters the first-stage turbine w/ a volumetric flow rate of 90 m³/min, exits to a constant pressure heater before entering a second-stage turbine. For a steady-state operation w/ negligible stray heat transfer, K.E. and P.E. effects, determine

a) (5) mass flow rate of the steam, in kg/s

b) (10) total power produced by the two-stage turbine, in kW

c) (10) rate of heat transfer to the steam flowing through the heater, in kW



a) $\dot{m} = \rho VA = \frac{VA}{v}$

@ $P_1 = 40$ bar, $T_1 = 500°C$

$v_1 = 0.08643$ m³/kg

$\dot{m} = 90 \frac{m^3}{min} \cdot \frac{1\ min}{60\ s} \cdot \frac{1}{v_1} = \boxed{17.36\ kg/s}$

b) $\cancel{\frac{dE}{dt}} = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \dot{m}[h_1 - h_2 + h_3 - h_4]$

$\dot{W}_{cv} = \dot{m}[(h_1 - h_2) + (h_3 - h_4)]$ +5

$\boxed{\dot{W}_{cv} = 17{,}565\ kW}$

$h_1 = 3445.3$ kJ/kg

$h_2 = 3247.6$ kJ/kg

$h_3 = 3467.6$ kJ/kg

$h_4 = 2653.5$ kJ/kg

+10

c) $\cancel{\frac{dE}{dt}} = \dot{Q}_{cv} - \cancel{\dot{W}_{cv}} + \dot{m}(h_2 - h_3)$

$\dot{Q}_{cv} = \dot{m}(h_3 - h_2) = \boxed{3{,}819\ kW}$

+5

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alternative for part (b), use both system as a single C.V. w/ $\dot{Q}$ in

$\cancel{\frac{dE}{dt}} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}(h_1 - h_4)$

$\dot{W}_{cv} = \dot{Q}_{cv} + \dot{m}(h_1 - h_4)$

4) 1.2 kg/s of water vapor enters a steady-state turbine at 5 bar, 320 °C and expands adiabatically to an exit state of 1 bar, 160 °C. K.E. and P.E. are negligible. For the turbine, determine

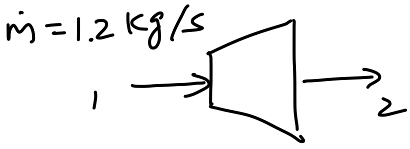
a) (5) the power developed, in kW

b) (5) the rate of entropy production, in kW/K

c) (10) the turbine efficiency

d) (5) draw the T-s diagram indicate all relevant states

6.138



	1	2
$\dot m$ (kg/s)	1.2	
P (bar)	5	1
T (°C)	320	160
h kJ/kg	3105.6	2796.2 (A-4)

+2

a)

$$\cancel{\frac{dE}{dt}} = \cancel{\dot Q_{cv}} - \dot W_{cv} + \dot m (h_1 - h_2)$$

+2

$$\dot W_{cv} = \dot m (h_1 - h_2) = \boxed{371.3\ kW}$$

b)

$$\cancel{\frac{ds}{dt}} = \oint \cancel{\frac{\delta \dot Q}{T}} + \dot m (s_1 - s_2) + \dot\sigma$$

$\dot\sigma = \dot m (s_2 - s_1)$ +2

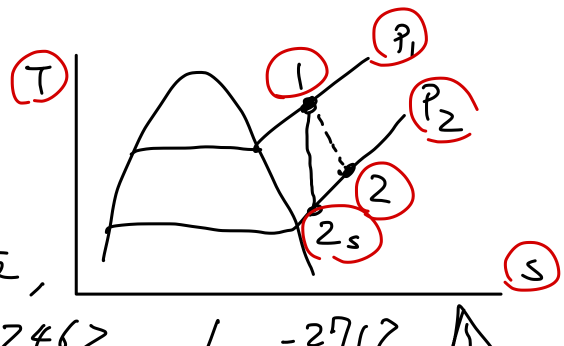
A-4 $s_1 = 7.5308\ \frac{kJ}{kg\cdot K}$

$s_2 = 7.6597$ " +2

$$\boxed{\dot\sigma = 0.155\ \frac{kW}{K}}$$

c)

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2s}}$$ +5



@ 1 bar, $s_{2s} = s_1 = 7.5308$, interpolate,

$h_{2s} = 2{,}743\ kJ/kg$ +2

$$\frac{7.531 - 7.467}{7.660 - 7.467} = \frac{h_{2s} - 2717}{2796 - 2717}$$

+2

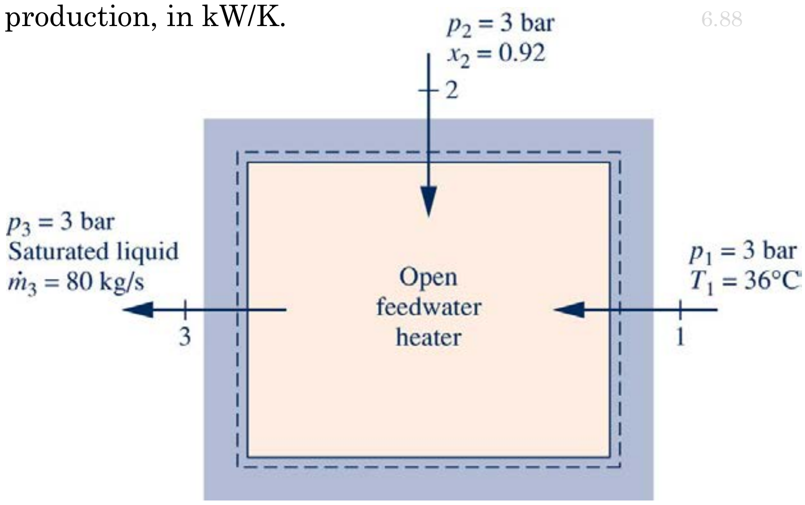
$$\eta = 0.853 = \boxed{85.3\%}$$

d)

−1 for each missing item

5) (15) An open feedwater heater is a direct-contact heat exchanger used in vapor power plants. With water as the working fluid at steady state, ignoring stray heat transfer from the heat exchanger to its surroundings, K.E. and P.E. effects, determine the rate of entropy production, in kW/K.

6.88



$$\cancel{\frac{dS}{dt}} = \cancel{\oint \frac{\delta Q}{T}} + \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{\sigma}_{cv} = 0$$

$$\dot{\sigma}_{cv} = \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m} s_2 \longrightarrow \text{need } \dot{m}_1 + \dot{m}_2$$

+3

mass: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ +2 $\quad \dot{m}_1 = \dot{m}_3 - \dot{m}_2$

energy: $\cancel{\frac{dE_{cv}}{dt}} = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3$

2 eqns → 2 unknowns

or

$0 = (\dot{m}_3 - \dot{m}_2) h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3$ +3

$\dot{m}_2 (h_1 - h_2) = \dot{m}_3 (h_1 - h_3)$

$$\dot{m}_2 = \dot{m}_3 \frac{(h_1 - h_3)}{(h_1 - h_2)}$$

basically if they have mass, energy, entropy eqn all correct ⇒ +8

	1	2	3
P(bar)	3	3	3
T °C	36		(134)
x		0.92	0
h kJ/kg	151	h_2	561.5
s kJ/kg K	0.519	s_2	1.672

+2

$h_2 = h_{f_2} + x_2 (h_{g_2} - h_{f_2}) = 2552$ kJ/kg

$s_2 = s_{f_2} + x_2 (s_{g_2} - s_{f_2}) = 6.566$ kJ/kg·K

$\dot{m}_2 = 13.68$ kg/s +2

$\dot{m}_1 = \dot{m}_3 - \dot{m}_2 = 66.32$ kg/s +2

$$\boxed{\dot{\sigma}_{cv} = 9.51 \text{ kW/K}}$$