Thermodynamics, MECH2010 Fall 2019, Test 3a 2019/12/05

Prof Fu-Lin Tsung

Name Chinese________________ Name, Pinyin _________________Student number ______________

Name, English____Soln____

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

Sign your name

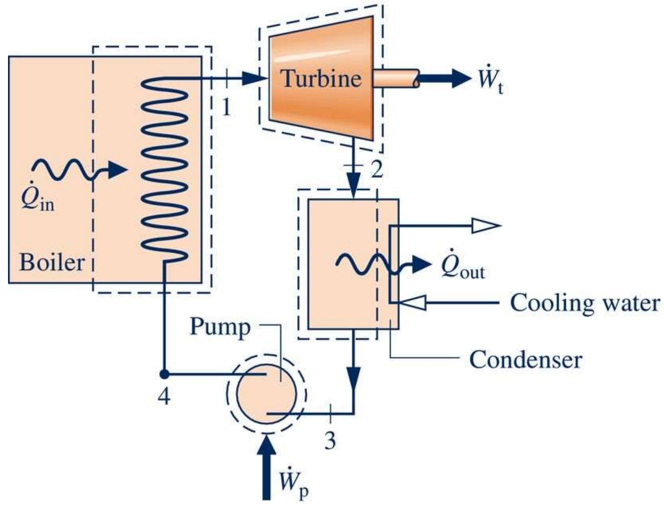
I, ________________________, will/did not cheat/copy any portion of this test.

(Pg 1)

$16\times10^6\ Pa\ \frac{1\ bar}{1\times10^5\ Pa} = 160\ bar$

1) (25) 120 kg/s of steam enters the turbine of an ideal Rankine cycle at 16 MPa, 560 °C. The condenser pressure is 8 KPa. The condenser cooling water undergoes a temperature increase of 15 °C with negligible pressure change.
Determine

a. The net power developed, in KW
b. The rate of heat transfer to the steam passing through the boiler, in KW
c. The thermal efficiency
d. The mass flow rate of the condenser cooling water, in kg/s, assuming the heat capacity of water is Cw = 4.18 kJ/kg-K (from Table A-19)



(=) on test

8.18

	P(bar)	T(°C)	h(kJ/kg)	s(kJ/kg-K)	x
1	160	560	3465.4	6.5132	
2s	0.08		2037.0	6.5132	0.7753*
3	0.08		173.88		0
4s	160		190.01		

+5

* $X_{2s} = \dfrac{S_{2s} - S_{2f}}{S_{2g} - S_{2f}} = 0.7753$

$h_{2s} = 2037\ kJ/kg$ Table look up

$h_{4s} \approx h_3 + v_3(P_4 - P_3)$

$173.88\ \frac{kJ}{kg} + (1.0084\times10^{-3})(160-0.08)\ \frac{m^3}{kg}\ bar\ \frac{10^5\ N/m^2}{bar}\ \frac{1\ kJ}{10^3\ N\cdot m}$

$= 190.01\ kJ/kg$

They can also go through s, h interpolation, more complicated / work, but similiar result

(Pg 2)

1) (25) 120 kg/s of steam enters the turbine of an ideal Rankine cycle at 16 MPa, 560 °C. The condenser pressure is 8 KPa. The condenser cooling water undergoes a temperature increase of 15 °C with negligible pressure change.

Determine

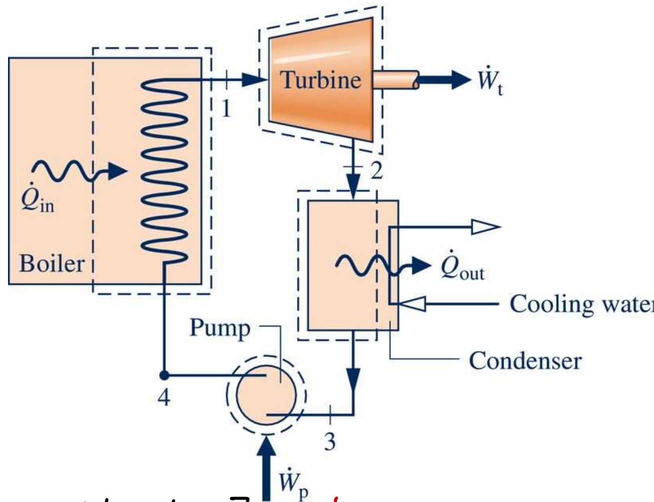
5 Properties

5 a. The net power developed, in KW

5 b. The rate of heat transfer to the steam passing through the boiler, in KW

3 c. The thermal efficiency

7 d. The mass flow rate of the condenser cooling water, in kg/s, assuming the heat capacity of water is Cw = 4.18 kJ/kg-K (from Table A-19)



a) $\dot{W}_{cycle} = \dot{W}_T - \dot{W}_p = \dot{m}[(h_1-h_2)-(h_4-h_3)]$ +4

$= 120\ \frac{kg}{s}\left[(3465-2037)-(190.-174.)\right]\frac{kJ}{kg} = \boxed{1.69\times10^5\ kW}$

b) $\dot{Q}_{in} = \dot{m}(h_1-h_4) = 120(3465-190) = \boxed{3.93\times10^5\ kW}$

+4

c) $\eta = \dfrac{\dot{W}_{cycle}}{\dot{Q}_{in}}\ \boxed{= 0.43 = 43\%}$

+2

d) $0 = \dot{m}_{cw}(h_5-h_6) + \dot{m}_w(h_2-h_3)$ +3

$dh = C_w\, dT$ +3

$dh = h_6-h_5 = 4.18(15)\frac{kJ}{kg\,K}(15\,K)$

$= 62.7\ \frac{kJ}{kg}$

$\dot{m}_{cw} = \dfrac{\dot{m}_w(h_3-h_2)}{-(h_6-h_5)} = \dfrac{120(173.88-2037)\frac{kJ}{kg}\frac{kg}{s}}{-62.7\ \frac{kJ}{kg}}$

$= \boxed{3566\ \frac{kg}{s}}$

$c = \frac{\delta Q}{dT}$

$\Delta U = Q - W = Q - \cancel{pdV}^{\,0}$

$h = u + pV$

$dh = du + p\cancel{dV}^{\,0} + v\cancel{dp}^{\,0}$

$dh = du$

$c = \frac{\delta u}{dT} = \frac{\delta h}{dT}$

(≡) on test

2) (15) For the previous problem, both the turbine and compressor efficiency is 85%,

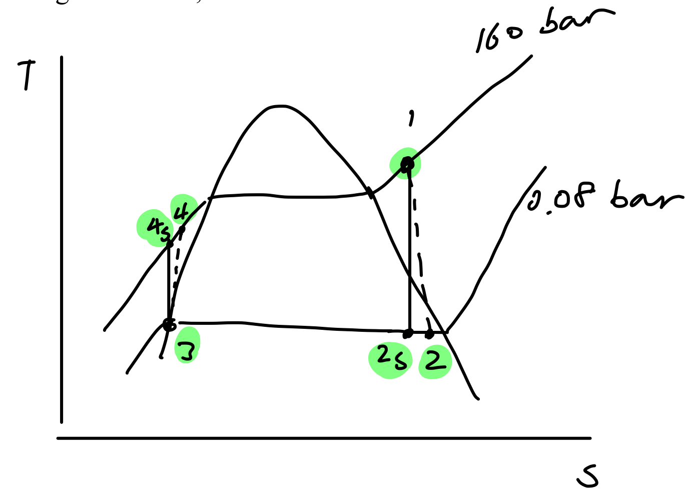
4 a. sketch the TS diagram for the problem (including the ideal process from the previous) determine

7 b. The net power developed, in KW

2 c. The rate of heat transfer to the steam passing through the boiler, in KW

2 d. The thermal efficiency

a)



b) $\eta_t = \dfrac{h_1 - h_2}{h_1 - h_{2s}}$ $h_2 = h_1 - \eta_t (h_1 - h_{2s})$ +3

$= 2251 \text{ kJ/kg}$ (2 phase)

$\dot{W}_{cycle} = \dot{W}_T - \dot{W}_p$

$\eta_p = \dfrac{h_{4s} - h_3}{h_4 - h_3}$ $h_4 = h_3 + \dfrac{h_{4s} - h_3}{\eta_p}$ +3

$= 193 \text{ kJ/kg}$

$\dot{W}_{cycle} = \dot{m}\left[(h_1 - h_2) - (h_4 - h_3)\right] = \boxed{1.434 \times 10^5 \text{ kW}}$

c) $\dot{Q}_{in} = \dot{m}(h_1 - h_4) = 120(3465.4 - 193) = \boxed{3.93 \times 10^5 \text{ kW}}$

d) $\eta = \dfrac{\dot{W}_{cycle}}{\dot{Q}_{in}} = \boxed{0.365 = 36.5\ \%}$

(III) (Pg 1)

3) (25) The inside temperature of a building is maintained at 22 °C by a heat pump using Refrigerant 134a (T-11: Saturated, T-12: Sup Vaper) while the average outside temperature is at 5 °C. Saturate vapor enters the compressor at -8 °C and exits at 50 °C, 10 bar. Saturated liquid exits the condenser at 10 bar. The steady refrigerant flow rate is 0.2 kg/s. ex10.4

8 a. Sketch the T-S diagram, labeling all states & temperatures required to solve the problem

Determine

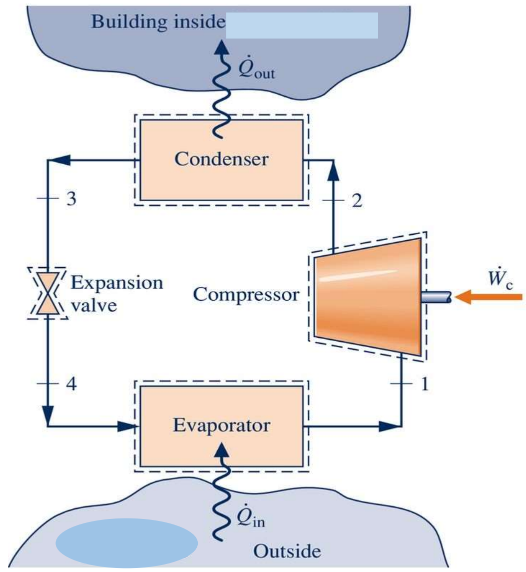
3 b. The compressor power, in KW

5 c. The isentropic compressor efficiency

3 d. The heat transfer rate provided to the building, in kW

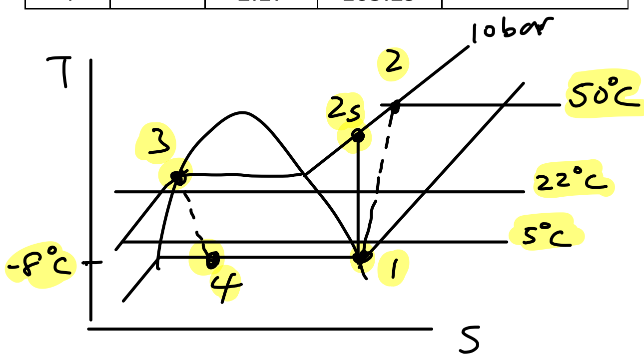
3 e. The coefficient of performance

3 f. The total cost of electricity, for 80 hrs of operation if electricity is 1 RMB per kW-h



State	T (°C)	p (bar)	h (kJ/kg)	s (kJ/kg-K)
1	-8	2.17	242.54	0.9239
2	50	10	280.19	-
3	-	10	105.29	-
4	-	2.17	105.29	-

a)



-1 For incorrect item in yellow

b) $\dot{W}_c = \dot{m}(h_2 - h_1) = 0.2 \frac{kg}{s}(280.2 - 242.5)\frac{kJ}{kg} = \boxed{7.53\ kW}$ +2

c) $\eta_c = \frac{(\dot{W}_c/\dot{m})_s}{(\dot{W}_c/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$ +2

$S_{2s} = S_1,\ P_2 \Rightarrow$ Table A12 $\Rightarrow h_{2s} = 274.2\ kJ/kg$ +2

Interpolate $\frac{0.9239 - 0.9066}{0.9428 - 0.9066} = \frac{h_{2s} - 268.68}{280.19 - 268.68}$

$\eta_c = \frac{274.2 - 242.54}{280.19 - 242.54} = \boxed{0.84\ (84\%)}$

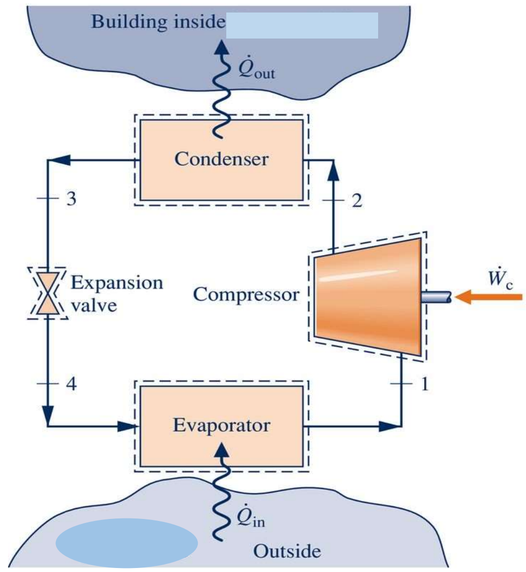
(Pg 2)

3) (25) The inside temperature of a building is maintained at 22 °C by a heat pump using Refrigerant 134a (T-11: Saturated, T-12: Sup Vaper) while the average outside temperature is at 5 °C. Saturate vapor enters the compressor at -8 °C and exits at 50 °C, 10 bar. Saturated liquid exits the condenser at 10 bar. The steady refrigerant flow rate is 0.2 kg/s. ex10.4

a. Sketch the T-S diagram, labeling all states & temperatures required to solve the problem

Determine

b. The compressor power, in KW
c. The isentropic compressor efficiency
d. The heat transfer rate provided to the building, in kW
e. The coefficient of performance
f. The total cost of electricity, for 80 hrs of operation if electricity is 1 RMB per kW-h



State	T (°C)	p (bar)	h (kJ/kg)	s (kJ/kg-K)
1	-8	2.17	242.54	0.9239
2	50	10	280.19	-
3	-	10	105.29	-
4	-	2.17	105.29	-

d) $\dot{Q}_{out} = \dot{m}(h_2 - h_3) = 0.2(280.2 - 105.3)$ +2

$= \boxed{35.0 \text{ kW}}$

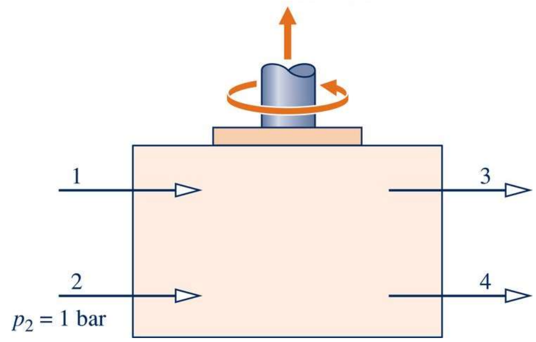
e) $\gamma = \dfrac{\dot{Q}_{out}}{\dot{W}_c} = \dfrac{35}{7.53} = \boxed{4.65}$ +2

f) $\text{cost} = (7.53 \text{ kW})(80 \text{ h})\left(\dfrac{1 \text{ RMB}}{\text{kW-h}}\right) = \boxed{602 \text{ RMB}}$ +2

from (b)

(-)

4) (20) A company claims at steady-state, the device shown develops power from entering and exiting streams of water at a rate of 1175 kW. The table provides data for openings 1, 3, and 4. The pressure at inlet 2 is 1 bar. Stray heat transfer, KE, and PE effects are negligible. Evaluate the claim.



State	m_dot (kg/s)	p (bar)	T (°C)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
1	4	1	450	3.334	3049.0	3382.4	8.6926
3	5	2	200	1.080	2654.4	2870.5	7.5066
4	3	4	400	0.773	2964.4	3273.4	7.8985

Needs to satisfy conservation of mass, energy, & 2nd Law

mass balance

$$\dot{m}_2 = \dot{m}_3 + \dot{m}_4 - \dot{m}_1 = 4 \text{ kg/s}$$

+4

1st Law

$$0 = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3 - \dot{m}_4 h_4$$

+4

$$h_2 = \frac{\dot{W}_{cv} - \dot{m}_1 h_1 + \dot{m}_3 h_3 + \dot{m}_4 h_4}{\dot{m}_2}$$

$$= \frac{1175 - 4(3382.4) + 5(2870.5) + 3(3273.4)}{4}$$

$$= 2955 \text{ kJ/kg}$$

+1

w/ P_2, h_2 → Table A4 → $s_2 = 7.995$ kJ/kg-K

+4

2nd Law

$$0 = \sum \cancel{\frac{\dot{Q}_j}{T_j}}^{\,0} + \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{m}_4 s_4 + \dot{\sigma}_{cv}$$

+4

$$\dot{\sigma}_{cv} = 5(7.5066) + 3(7.8985) - 4(8.6926) - 4(7.995)$$

$$= -5.52 \frac{\text{kJ/s}}{\text{K}}$$

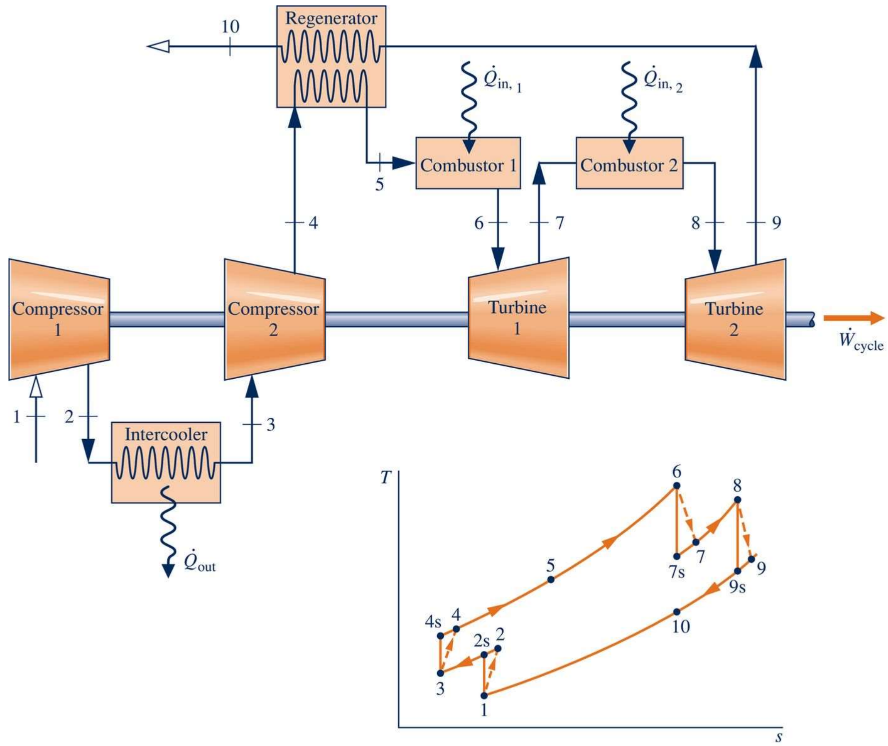
+1

$\dot{\sigma}_{cv}$ cannot be negative. False

+2

(3)

5) The figure for a regenerative Gas turbine with intercooling and reheat along w/ its T-s diagram is shown



Write the equation for

a) the total turbine work per unit of mass flow
b) the total compressor work input per unit of mass flow
c) the total heat **added to the cycle** per unit of mass flow (i.e. draw a system boundary)
d) the thermo efficiency of the cycle
e) back work ratio

a) $\frac{\dot{W}_T}{\dot{m}} = (h_6 - h_7) + (h_8 - h_9)$ +3

b) $\frac{\dot{W}_c}{\dot{m}} = (h_2 - h_1) + (h_4 - h_3)$ +3

c) $\frac{\dot{Q}_{in}}{\dot{m}} = (h_6 - h_5) + (h_8 - h_7)$ +3

d) $\frac{\dot{W}_{cycle}}{\dot{Q}_{in}} = \eta = \frac{\dot{W}_T - \dot{W}_c}{\dot{Q}_{in}}$ +3

$$= \frac{(h_6 - h_7) + (h_8 - h_9) - (h_2 - h_1) - (h_4 - h_3)}{(h_6 - h_5) + (h_8 - h_7)}$$

e) $BWR = \frac{\dot{W}_c}{\dot{W}_T} = \frac{(h_2 - h_1) + (h_4 - h_3)}{(h_6 - h_7) + (h_8 - h_9)}$

+3