AREN 2110
Spring 2011

EXTRA CREDIT OPPORTUNITY: Due end of day, Friday, April 29

The purpose of these extra credit problems is to give you structured practice in preparing for the final. It is also an opportunity to improve your test scores (or be an "insurance policy" for your final exam grade). There are 20 multiple choice or short answer questions in the following pages, each worth 1 point (no partial credit). The points for all correct answers will be added directly to your total test score (comprised of the two midterms and the final). Each midterm was 50 points, and the final will be 75 points, for a total of 175 points for tests. (Homework grades will be scaled to count for another 75 points.) For example, if you received scores of 30/50 on midterm 1, 40/50 on midterm 2, and 55/75 on the final exam and answered 15 extra credit questions correctly, your total point score for the exam component of your grade would be: 30 + 40 + 55 + 15 = 140/175, for a test average of 80%. This would be a significant improvement over your total test score without extra credit = 125/175, average = 71.4%. The application of the extra credit will have a ceiling so that no one gets an average of over 100% for the three tests. Of course, if you are satisfied with your test score and preparation you do not have to do any of these problems.

INSTRUCTIONS: the questions are open book and notes, but **you must do them on your own – no consulting with other students, TA or former students.** Show all your work. **Questions involve some computation or explanation and you will not receive credit for an answer if you do not show your work, i.e., there is no credit for guessing.** You are encouraged to do your work on separate sheets and attach when you hand in. If you have questions, see Prof. Silverstein. Please sign the honor code statement below before turning in your answers, indicating that you have not received any unauthorized assistance.

Name (print) SOLUTIONS

I have read, understand, and agree to abide by the University of Colorado honor code in this test context:

I have neither given nor received unauthorized assistance during this examination.

Signed:____________________

Score: ________**/20 points possible**

1. A refrigerator supplies 5 kw cooling for a cold space maintained at -5 °C and rejects heat at a rate of 5.5 kw to a room kept at 25 °C. The compressor motor provides 500 w of power. The refrigerator satisfies:

[✓ a) 1st Law only]
b) 2nd Law only
c) 1st and 2nd Laws
c) Neither 1st or 2nd Law

For problems 2-4, a Carnot heat engine operates with high and low temperature reservoirs at 300 °C and 15 °C, respectively. The change in entropy of the working fluid in the isothermal expansion process is 2.4511 kJ/kg-K

2. The cycle efficiency is

a) 0.25
[✓ b) 0.50]
c) 0.75
d) 0.95

3. Heat is rejected at a rate of

a) 38 kJ/kg
b) 288 kJ/kg
[✓ c) 706 kJ/kg]
d) 1,404 kJ/kg

4. The net work output from the heat engine is

[✓ a) 699 kJ/kg]
b) 706 kJ/kg
b) 1,383 kJ/kg
d) 1,404 kJ/kg

5. Entropy is "conserved:"

a) Never
b) In a cycle only
[✓ b) In a reversible process]
d) In an isothermal process

6. Air is expanded in an isentropic turbine. The inlet pressure is 2 MPa and the outlet pressure is 100 kPa. The outlet temperature is 17 °C. The inlet temperature is:

a) 40 °C
b) 340 °C
[✓ c) 410 °C]
d) 5530 °C

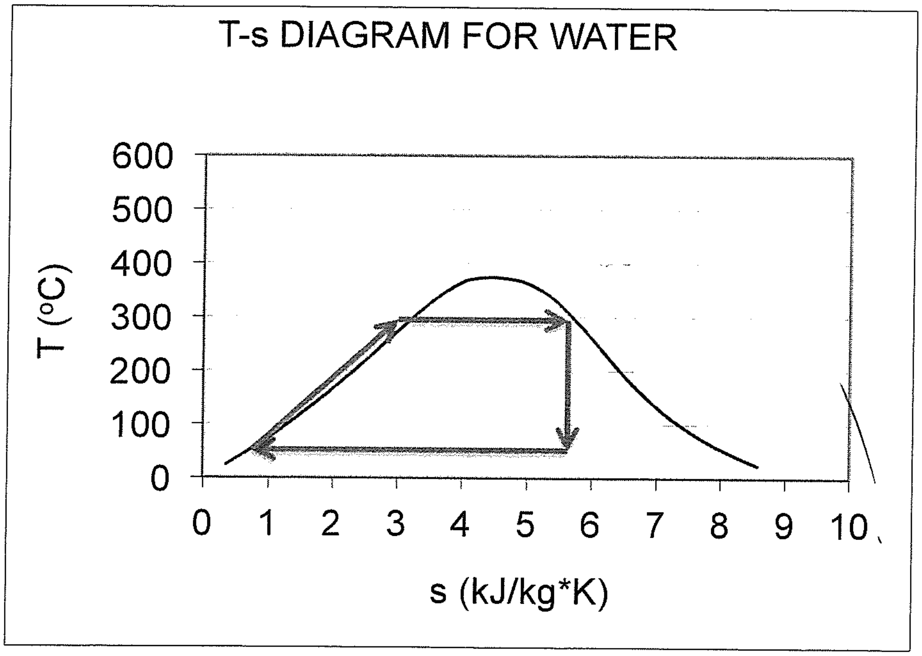
A steady flow of

7. 5 kg/s of saturated refrigerant vapor is condensed in an internally reversible process to saturated liquid in an isobaric heat exchanger at 900 kPa. Heat is rejected to the surroundings at 15 °C. The entropy generated in the universe is:

[✓ a) ~~5.6 kw/K~~] 2b b) 2.7 kw/K

c) -0.2 kw/K 2 kW/K d) Zero

For questions 8 – 11. The T-s diagram below represents an ideal Rankine power generation cycle with a boiler pressure = 8.6 MPa and a condenser pressure = 12.4 kPa. Water at the turbine inlet is saturated vapor and saturated liquid at the condenser outlet.



8. The quality of the steam at the turbine outlet is 0.678.

9. The cycle efficiency is 0.362.

10. A 100 MW plant is to be designed. The required mass flow rate of steam is:

109 Kg/s

11. The required mass flow rate of condenser cooling water with a maximum temperature increase of 7 °C is:

5,981 kJ/s

12. Water is pumped to the boiler of a power plant in an adiabatic and reversible process. State properties that DO NOT CHANGE from inlet to outlet are:

a) s

b) s and h

c) s and T

[✓ d) s, T, and v]

13. Which of the following conditions will improve the coefficient of performance of a heat pump?

[✓ a) Increasing T_L]

b) Increasing T_H

c) Increasing power input

d) Lowering evaporator pressure.

14. A throttling valve is used to reduce the pressure of saturated liquid R-134a from 1.2 MPa to 120 kPa. During the process, 25 kJ/kg heat is lost to the surroundings at 20 °C. The entropy of the R-134a at the outlet is:

[✓ a) 0.373 kJ/kg-K]

b) 0.424 kJ/kg-K

c) 0.469 kJ/kg-K

d) 0.572 kJ/kg-K

15. The velocity of helium increases from 30 to 500 m/s as it flows through a nozzle in an isothermal process. The pressure of the helium at the inlet is 100 kPa and 85 kPa at the outlet. This process is:

$T_{surr} = 17^\circ C$

a) adiabatic

b) isentropic

c) reversible

[✓ d) impossible]

16. Steam at 200 kPa and 200 °C is mixed adiabatically with cold water at the same pressure and 25 °C to produce 1 kg/s saturated liquid water at 200 kPa. The rate of entropy generation in the surroundings is:

a) 0.055 kw/K

[✓ b) 0.128 kw/K]

c) 0.222 kw/K

d) 0.277 kw/K

17. What is the minimum heat load to a room maintained at 21 °C from a refrigerator keeping the cold box at 0 °C by removing heat at a rate of 12 kw?

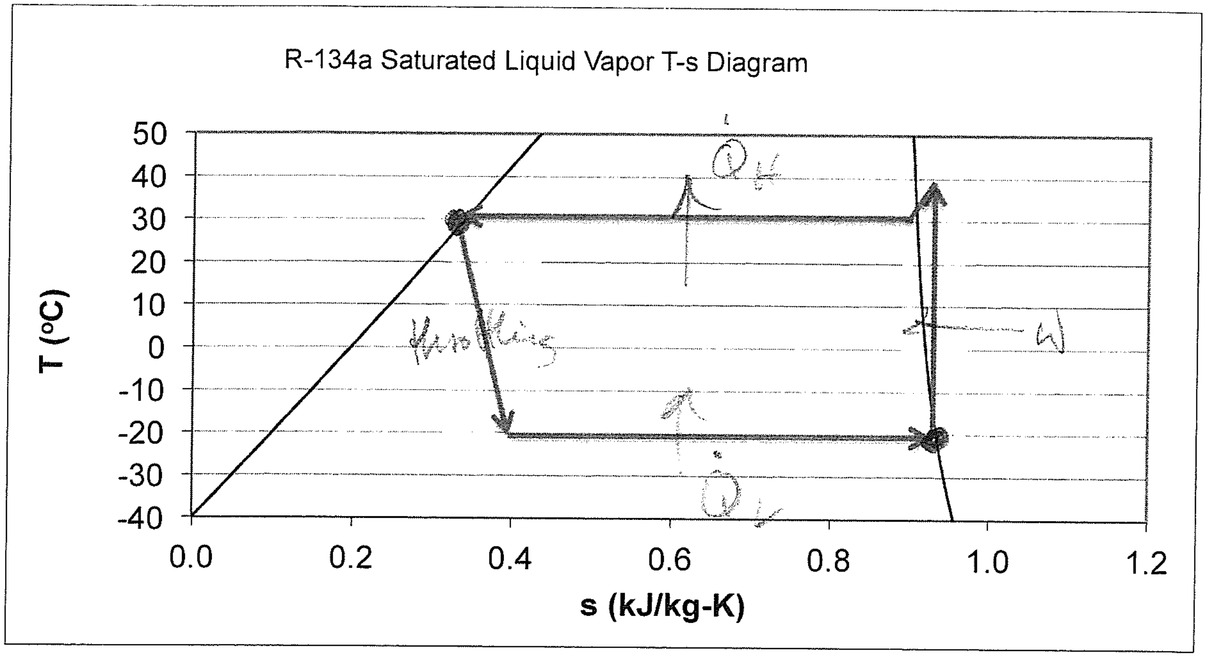
a) 11 kw

b) 12 kw

[✓ c) 13 kw]

d) 14 kw

For questions 18 – 20. A heat pump operates with an ideal vapor-compression refrigeration cycle. The evaporator pressure is 120 kPa and the condenser pressure is 800 kPa. R-134a is saturated vapor at the inlet to the adiabatic and reversible compressor and saturated liquid at the inlet to the adiabatic throttling valve.



18. Calculate the work input to the compressor (kJ/kg). (You do not need to interpolate, you may round the entropy value at the compressor inlet to 3 significant figures.)

39.5 kJ/kg

19 . Calculate the coefficient of performance of the heat pump.

4.6

20. Calculate the entropy generated in the surroundings by the heat pump for a room at 20 °C and air at an average temperature of 5 °C as the heat source.

0.109 $\frac{kJ}{kg\,K}$

1. 1st Law $\quad \dot{W} = \dot{Q}_H + \dot{Q}_L$

$$-0.5\,kW = -5.5\,kW + 5\,kW$$

$$5\,kW = 5\,kW \checkmark \quad \text{satisfies 1st Law}$$

2nd Law $\quad COP_{CR} = \dfrac{1}{\frac{T_H}{T_L} - 1} = \dfrac{1}{\frac{298}{268} - 1} = 8.9$

$$COP_R = \frac{5}{0.5} = 10 > COP_{CR} \; \boxed{\text{violates 2nd Law}}$$

2. $\eta_c = 1 - \dfrac{T_L}{T_H} = 1 - \dfrac{288}{573} = \boxed{0.50}$

3. $q_L = T_L(\Delta s) = 288K(2.4511)\dfrac{kJ}{kgK} = \boxed{706\,kJ/kg}$

4. $w_{net} = q_H + q_L = 573K(2.4511)\dfrac{kJ}{kg} - 706$

$$\boxed{= 699\,kJ/kg}$$

5. $\Delta s = \dfrac{q}{T} + \cancelto{0}{S_{gen}}$

Δs is accounted for (conserved) by $\dfrac{q}{T}$ in a reversible process

6. ideal gas, isentropic process

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \quad \text{where } k = c_p/c_v = 1.4 \text{ for air}$$

$$T_1 = T_2\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} = 290K(20)^{0.4/1.4} = 683K$$

$$\boxed{= 410°C}$$

7. $\dot{m}\Delta s = \dfrac{\dot{Q}}{T} + \dot{S}_{gen}$ $\qquad$ 1st Law: $\dot{Q} = \dot{m}(-h_{fg})$ @ 900kPa

$$\dot{S}_{gen} = 5\frac{kg}{s}\left(0.54315\frac{kJ}{kgK}\right) - \left(\frac{-838.3}{288}\right) \qquad = 5\,kg/s(-167.66)\,kJ/kg$$

$$= -838.3\,kW$$

$$\dot{S}_{gen} = \boxed{5.6\,kW/K}$$

8. $s_3 = s_g @ 300°C = 5.7059 \text{ kJ/kgK}$

$= s_4, \quad x_4 = \dfrac{5.7059 - s_{f,50°C}}{s_{fg,50°C}} = \dfrac{5.7059 - 0.7038}{7.371}$

$\boxed{x_4 = 0.678}$

9. $\eta = 1 - \dfrac{h_4 - h_1}{h_2 - h_3}$

$= 1 - \dfrac{(1824.3 - 209.34)}{2749.3 - 218}$

$\boxed{\eta = 0.362}$

$h_1 = h_f @ 50°C = 209.34$

$h_2 = h_1 + v(8600 - 12.4)$

$= 209.34 + 0.001012(\underbrace{8600 - 12.4}_{8.7})$

$= 218.0$

$h_3 = h_g @ 300°C = 2749.6 \text{ kJ/kg}$

$h_4 = 0.678(2382) + 209.34$

$= 1824.3$

10. $\dot{W}_{net} = 100 \text{ MW}$

$100 \text{ MW} = \dot{m}(\eta)(h_3 - h_2)$

$\dot{m}_s = \dfrac{100{,}000 \text{ kJ/s}}{0.362(2749.3 - 218)} = \boxed{109 \text{ kg/s}}$

11 $\dot{m}_w = \dfrac{\dot{Q}_L}{4.184(7)} = \dfrac{\dot{m}_s(h_4 - h_1)\text{ kJ/s}}{4.184(7)\ \frac{\text{kJ}}{\text{kg}}} = \dfrac{109(1824.3 - 218)}{4.187(7)}$

$\boxed{\dot{m}_w = 5{,}981 \dfrac{\text{kg}}{\text{s}}}$

12. incompressible liquid $\rightarrow \Delta v = 0$

reversible + adiabatic $\rightarrow \Delta s = 0 = c \ln\left(\dfrac{T_2}{T_1}\right)$

$T_2 = T_1 \qquad \rightarrow \Delta T = 0$

13. $COP_{CHP} = \dfrac{1}{1 - \dfrac{T_L}{T_H}}$

$\boxed{\text{increase } T_L, \ COP_{HP} \uparrow}$

increase T_H, $COP_{HP} \downarrow$

increase $\dot{W}$, $COP = \dfrac{\dot{Q}_H}{\dot{W}} \downarrow$

real heat pumps

follow CARNOT trend

lower evap P, T_L decreases, COP $\downarrow$

14. throttling valve $\quad$ 1st Law $\quad h_1 = h_{f@} = 117.77\ \text{kJ/kg}$

$$h_2 = -25\ \frac{\text{kJ}}{\text{kg}} + 117.77\ \text{kJ/kg} = 92.77\ \text{kJ/kg}$$

$$x_2 = \frac{92.77 - 22.49}{214.48} = 0{,}328$$

$$s_2 = 0{,}328(0.85503) + 0.09275 = \boxed{0.373}$$

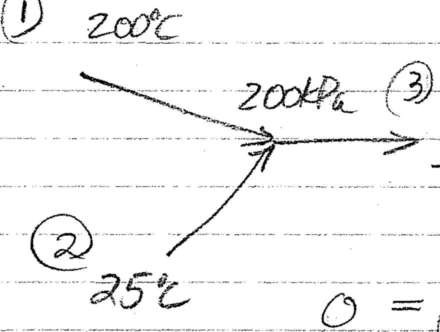
15. $$\underset{0}{q} - \underset{0}{w} = \frac{V_2^2 - V_1^2}{2000} = \frac{500^2 - 30^2}{2000} = \underset{0}{q} = 124.55\ \frac{\text{kJ}}{\text{kg}}$$

$$\Delta s = \underset{0}{C_p \ln\left(\frac{T_2}{T_1}\right)} - R\ln\left(\frac{P_2}{P_1}\right) = -2.0769\ \ln\left(\frac{85}{100}\right) = +0.34\ \text{kJ/kgK}$$

$$s_{gen} = -\frac{124.55}{290} + 0.34\ \frac{\text{kJ}}{\text{kgK}}$$

$$= -0.09\ \text{kJ/kgK} < 0$$ impossible

16.



$\dot m_3 = 1\ \text{kg/s} = \dot m_2 + \dot m_1$

$x = 0$

$T_3 = T_s = 120.21°C$

$$0 = (\dot m_1 + \dot m_2)(h_3) - \dot m_1 h_1 - \dot m_2 h_2$$

$$= \dot m_1 (h_3 - h_1) + \dot m_2 (h_3 - h_2)$$

$$= \frac{\dot m_1}{\dot m_2}(504.71 - 2870.7)\ \frac{\text{kJ}}{\text{kg}} + (504.71 - 104.83)$$

$$\frac{\dot m_1}{\dot m_2} = \frac{-(504.71 - 104.83)}{(504.71 - 2870.7)} = 0.17$$

$$\dot m_3 = 1\ \text{kg/s} = \dot m_2 + 0.17\dot m_2$$

$$\dot m_2 = 0{,}855\ \text{kg/s}$$

$$\dot m_1 = 0.145\ \text{kg/s}$$

16. $S_{gen} = 1\,kg/s\,(1.5302) - 0.855(0.3672) - 0.145(7.5081)$

$= \boxed{0.128\,\frac{kW}{K}}$

17. $COP_{CR} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{1}{\frac{294}{273} - 1} = 13$

$\dot{Q}_L = 12\,kW$

$\dot{W}_{min} = \frac{12\,kW}{13} = 0.923\,kW$

$\dot{Q}_{H_{min}} = -0.923\,kW - 12\,kW = -12.923\,kW$

$\boxed{\simeq 13\,kW \text{ heat load}}$

18. $-W = h_2 - h_1$

$h_1 = h_g$ @ 120kPa

$= 236.97\,kJ/kg$

$s_1 = 0.94779 \cong s_2$

$-W = 276.45 - 236.97$

$\boxed{= 39.5\,kJ/kg}$

@ 800kPa & 40°C, $s_2 = 0.948$ close enuff

$h_2 = 276.45$

$h_3 = h_f$ @ 800 kPa

$= 95.47\,kJ/kg$

19. $COP = \frac{q_H}{w} = \frac{h_2 - h_3}{39.5} =$

$COP_{HP} = \frac{276.45 - 95.47}{39.5} \boxed{= 4.6}$

20. $\Delta S_{cycle} = 0$

$S_{gen} = -\frac{q_H}{T_H} - \frac{q_L}{T_L}$

$q_L = 236.97 - 95.47$

$= 141.5\,kJ/kg$

$S_{gen} = -\left(\frac{-181}{293}\right) - \frac{141.5}{278} \boxed{= 0.109\,\frac{kJ}{kg\,K}}$