

AREN 2110 THERMODYNAMICS

FINAL Examination

December 2006

Name, Nom, Nombre _____

Solutions

PRINT

Examination Time is ^{2.5 hr} ~~75 minutes~~. This examination is open book and open notes

Point value for each problem is written next to the problem label in parentheses (e.g. (3)).

SCORE

1. _____ (25)

2. _____ (25)

3. _____ (25)

4. _____ (25)

Σ . _____ (100)

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: _____

1. (25 points) Answer the following by circling the best answer and/or providing a simple calculation .

1) (5) Any **adiabatic and reversible** unit process is always:

- (a) isochoric
- (b) isobaric
- (c) isolatent
- (d) isentropic
- (e) isothermal
- (f) isometric

2) (5) Entropy is always transferred with heat, and was defined by Clausius as the **ratio**:

- (a) Heat Transferred: Absolute Temperature of the Surroundings
- (b) Heat Transferred: Net Work
- (c) Heat Transferred: Boundary Work
- (d) Latent Heat: Absolute Temperature of the Surroundings
- (e) Enthalpy: Boundary Work
- (f) Specific Heat: Absolute Temperature of the Surroundings

$$s_{transfer} = \frac{Q}{T}$$

3) (5) Steam is expanded in a **reversible** turbine which loses heat to the surroundings. The entropy of the steam will always

- (a) Increase in proportion to heat transferred
- (b) Decrease in proportion to heat transferred
- (c) Equal the entropy generated in the surroundings
- (d) Stay the same
- (e) Cannot be determined
- (f) Decrease in proportion to the work produced

$$s_2 - s_1 = \frac{q}{T}$$

$$= (-)$$

$$s_2 - s_1 < 0, s_2 < s_1$$

4) (5) The entropy of an ideal (incompressible) liquid or solid undergoing an **isothermal** process:

- (a) always increases
- (b) depends on the heat transferred
- (c) depends on the specific heat of the substance
- (d) depends on the change in pressure
- (e) always decreases
- (f) always stays the same

$$(s_2 - s_1)_{\text{liquid/solid}} = c_p \ln \frac{T_2}{T_1}$$

if $T_2 = T_1, s_2 - s_1 = 0$

5) (5) One of Carnot's principles states:

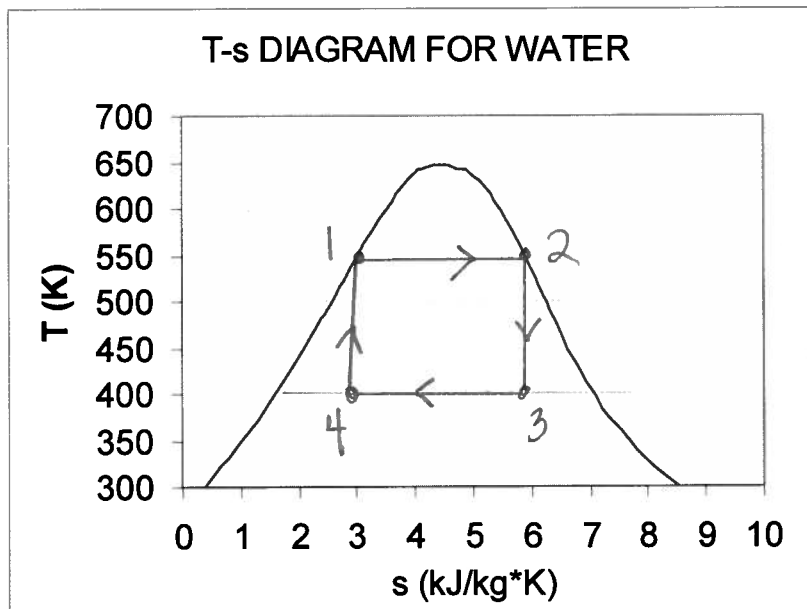
- (a) $PV = mRT$
- (b) Entropy is conserved
- (c) Reversible heat engines operating between the same thermal reservoirs have the same efficiency
- (d) Any heat engines operating between the same thermal reservoirs have the same efficiency
- (e) Efficiency of a heat engine is the ratio of the work produced to the heat rejected

2. (25 points) Consider a Carnot heat engine using water/steam as the working fluid, and having an efficiency of 28%. Heat is transferred to the working fluid at 280 °C, and during this process, the working fluid changes from saturated liquid to saturated vapor.

a) (10) Complete the table below and show the cycle on the T-s diagram.

	1	2	3	4
T (K)	553	553	398	398
s (kJ/kg-K)	3.0688	5.8571	5.8571	3.0688

Number the beginning end process states to be consistent with the table and use arrows to indicate process direction on the diagram.



$$0.28 = 1 - \frac{T_L}{553}$$

$$T_L = 398\text{K} = 125^\circ\text{C}$$

b) (10) Calculate the quality at the beginning and end of the heat rejection process

$$x_3 = \frac{5.8571 - s_f @ 125^\circ\text{C}}{s_{fg}} = \frac{5.8571 - 1.5813}{5.4962} = 0.79$$

$$x_4 = \frac{3.0688 - s_f @ 125^\circ\text{C}}{s_{fg}} = \frac{3.0688 - 1.5813}{5.4962} = 0.27$$

c) (5) Calculate the specific net work of the cycle.

$$W_{net} = q_{net} = (T_1 - T_4)(s_2 - s_1)$$

$$= (280 - 125)(5.8571 - 3.0688) = 432 \frac{\text{kJ}}{\text{kg}}$$

d) (5) Calculate the specific rejected heat $q_L = T_4 (s_4 - s_3) = 398(3.0688 - 5.8571) = -1110 \text{ kJ/kg}$

3. (25 points) A continuous flow device compresses air in a steady-state process with an inlet flow rate of $60 \text{ m}^3/\text{min}$. The initial pressure is 100 kPa at 27°C and the final pressure is 400 kPa at 120°C . The compressor loses 50 kJ/kg heat to the surroundings (at the same temperature as the inlet air).

a) (5) Calculate the power (in kw) required for the compressor, neglecting kinetic energy changes.

$$\dot{m} = \rho \dot{V} = \frac{P}{RT_1} \dot{V}_1 = \frac{100 \left(\frac{60}{60}\right)}{0.287(300)} = 1.16 \text{ kg/s}$$

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) = \dot{m} c_p (T_2 - T_1)$$

$$\dot{m} q - \dot{W} = \dot{m} c_p (T_2 - T_1) = -50(1.16) - \dot{W}$$

$$-\dot{W} = 1.16 \frac{\text{kg}}{\text{s}} \left[1.008 \frac{\text{kJ}}{\text{kgK}} (120 - 27) + 50 \right]$$

$$-\dot{W} = 168 \text{ kW}$$

$$\dot{W} = -168 \text{ kW (input)}$$

b) (5) Calculate the change in the entropy of the air as it passes through the compressor (kw/K).

$$\dot{m}(s_2 - s_1) = \dot{m} \left[c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) \right]$$

$$= 1.16 \frac{\text{kg}}{\text{s}} \left[1.008 \ln\left(\frac{393}{300}\right) - 0.287 \ln\left(\frac{400}{100}\right) \right]$$

$$\dot{m}(s_2 - s_1) = -0.146 \frac{\text{KW}}{\text{K}}$$

c) (5) Calculate the entropy generated in the surroundings (kw/K).

$$\dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1) - \frac{\dot{Q}}{T} = -0.146 - \left(\frac{-50(1.16)}{300} \right)$$

$$\dot{S}_{\text{gen}} = 0.0475 \frac{\text{KW}}{\text{K}}$$

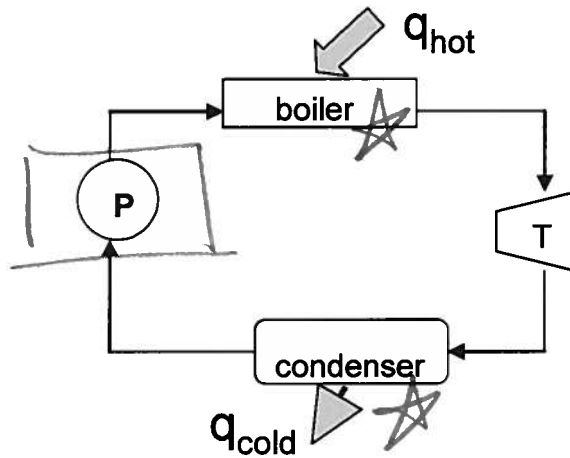
d) (5) Is this process reversible? Justify your answer.

No, $\dot{S}_{\text{gen}} > 0$

e) (5) Would the compressor work to these specifications if it were designed to be adiabatic? Justify your answer.

No, for adiabatic compressor, $\dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1) = -0.1257 \frac{\text{kw}}{\text{K}}$
process would be impossible for $\dot{S}_{\text{gen}} < 0$

4. (25 points) Please refer to the ideal Rankine cycle diagram below for a power plant with saturated liquid at the condenser outlet: 60 kg/s of steam flows through system, which operates between the pressure limits of 3 MPa and 50 KPa. The temperature at the turbine inlet is 400 °C.



a. (5) Draw a star next to all processes where energy transfer is proportional to the latent heat of water/steam.

heat transfer for boiling and condensations

b. (5) Draw a box around any **adiabatic** unit process where the enthalpy of the working fluid **increases**. Calculate the enthalpy increase during this process.

$$h_2 - h_1 = w_p = v (P_2 - P_1)$$

$$= 0.00103 (3000 - 50)$$

$$h_2 - h_1 = 3.04 \text{ kJ/kg}$$

c. (10) Calculate the thermal efficiency of the cycle.

$$h_1 = h_f @ 50 = 340.49$$

$$h_2 = 340.49 + 3.04 = 343.53 \text{ kJ/kg}$$

$$h_3 = 3230.9 \text{ kJ/kg (A-6 @ 3 MPa \& 400^\circ\text{C})}$$

$$s_3 = s_4 = 6.9212 \text{ kJ/kgK}$$

$$x_4 = \frac{6.9212 - 1.091}{6.5029} = 0.897$$

$$h_4 = 0.897(2305.4) + 340.49 = 2407.4 \text{ kJ/kg}$$

$$\eta = 1 - \frac{(h_4 - h_1)}{(h_3 - h_2)} = 1 - \frac{(2407.4 - 340.49)}{(3230.9 - 343.53)} = 0.284 \text{ (28.4\%)}$$

d. (5) Calculate the net power output (in kw) of this cycle under the operating conditions given.

$$\dot{W}_{net} = \eta \dot{m} (h_3 - h_2) = 0.284 \left(\frac{60 \text{ kg}}{s} \right) (3230.9 - 343.53)$$

$$\dot{W}_{net} = 49,227 \text{ kW}$$

$$\sim 49.2 \text{ MW}$$