Clean Energy Research Centre (www.cerc.ubc.ca)
University of British Columbia

CEEN 501 Thermal Energy Systems

Quiz #3 (November 6, 2013)

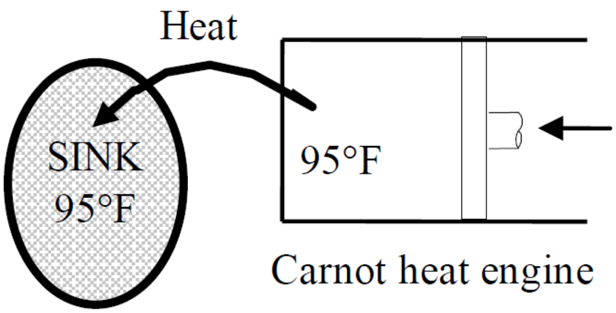
Name ________________________

Student # ________________________

- **Closed book & closed computer.**
- **Calculator required.**
- **Show all your work on these pages (no extra pages please).**
- **There are five (5) questions with point distribution as follows:**

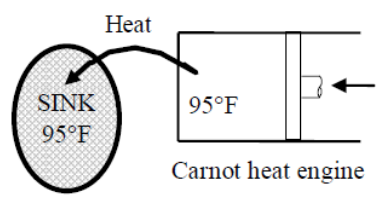
problem	points
1	12
2	4
3	12
4	6
5	6
total	**40**

1. During the isothermal heat rejection process of a Carnot cycle, the working fluid experiences an entropy change of - 0.7 Btu/R. The temperature of the heat sink is 95°F. Determine a) the amount of heat transfer (Btu), b) the entropy change of the sink (Btu/R), and the total entropy change for this process (Btu/R).



CCT 8-28E

8-28E Heat is transferred isothermally from the working fluid of a Carnot engine to a heat sink. The entropy change of the working fluid is given. The amount of heat transfer, the entropy change of the sink, and the total entropy change during the process are to be determined.



Analysis (*a*) This is a reversible isothermal process, and the entropy change during such a process is given by

$$\Delta S = \frac{Q}{T}$$

Noting that heat transferred from the working fluid is equal to the heat transferred to the sink, the heat transfer become

$$Q_{\text{fluid}} = T_{\text{fluid}}\Delta S_{\text{fluid}} = (555\ \text{R})(-0.7\ \text{Btu/R}) = -388.5\ \text{Btu} \rightarrow Q_{\text{fluid,out}} = \mathbf{388.5\ Btu}$$

(*b*) The entropy change of the sink is determined from

$$\Delta S_{\text{sink}} = \frac{Q_{\text{sink,in}}}{T_{\text{sink}}} = \frac{388.5\ \text{Btu}}{555\ \text{R}} = \mathbf{0.7\ Btu/R}$$

(*c*) Thus the total entropy change of the process is

$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{fluid}} + \Delta S_{\text{sink}} = -0.7 + 0.7 = \mathbf{0}$$

This is expected since all processes of the Carnot cycle are reversible processes, and no entropy is generated during a reversible process.

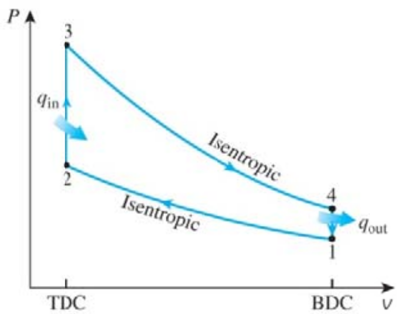
2. Nitrogen gas at 900 kPa and 300°C is expanded adiabatically in a closed system to 100 kPa. Determine the minimum nitrogen temperature after expansion. Assume an ideal gas, constant specific heats, and a specific heat ratio of 1.391.

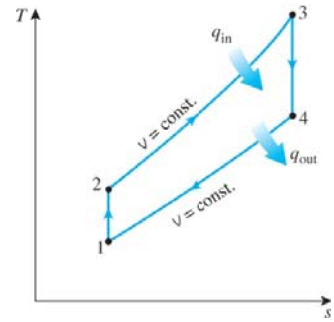
   Adapted from CCT 8-80

Analysis From the isentropic relation of an ideal gas under constant specific heat assumption,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300+273\text{ K})\left(\frac{100\text{ kPa}}{900\text{ kPa}}\right)^{0.391/1.391} = \mathbf{309\ K}$$

3. An ideal Otto cycle is illustrated in the figures below. The cycle has a compression ratio of 8, P_1 = 95 kPa, T_1 = 15.0 °C, T_2 = 388.5 °C, T_4 = 368.0 °C and maximum cycle temperature of 1200.0 °C. Calculate a) the heat addition (kJ/kg), b) the heat rejected (kJ/kg), and c) thermal efficiency of the cycle.





Recall that an ideal Otto cycle uses air standard assumptions. Neglect changes in kinetic and potential energies. Assume ideal gas with constant specific heats.
Properties are:
R =0.287 kPa m^3 / kg · K
Cv= 0.718 kJ / kg · K
Cp = 1.005 kJ / kg · K
K = 1.4

Adapted from CCT 9-34

T_1 = 15.0 + 273.2 = 288.2 K
T_2 = 388.5 + 273.2 = 661.7 K
T_3 = 1200.0 + 273.2 = 1473.2 K
T_4 = 368.0 + 273.2 = 641.2 K

First law for a closed system process (neglecting Δke and Δpe):

$$(q_{,in} - q_{,out}) - (w_{,in} - w_{,out}) = \Delta u$$

Thermal efficiency of a heat engine:

$$\eta_{th} = \frac{w_{net,out}}{q_H} = 1 - \frac{q_L}{q_H}$$

Application of the first law to the heat addition process gives

$$q_{in} = c_v(T_3 - T_2) = (0.718\,\text{kJ/kg}\cdot\text{K})(1473 - 661.7)\text{K} = \mathbf{582.5\ kJ/kg}$$

Similarly, the heat rejected is

$$q_{out} = c_v(T_4 - T_1) = (0.718\,\text{kJ/kg}\cdot\text{K})(641.2 - 288)\text{K} = \mathbf{253.6\ kJ/kg}$$

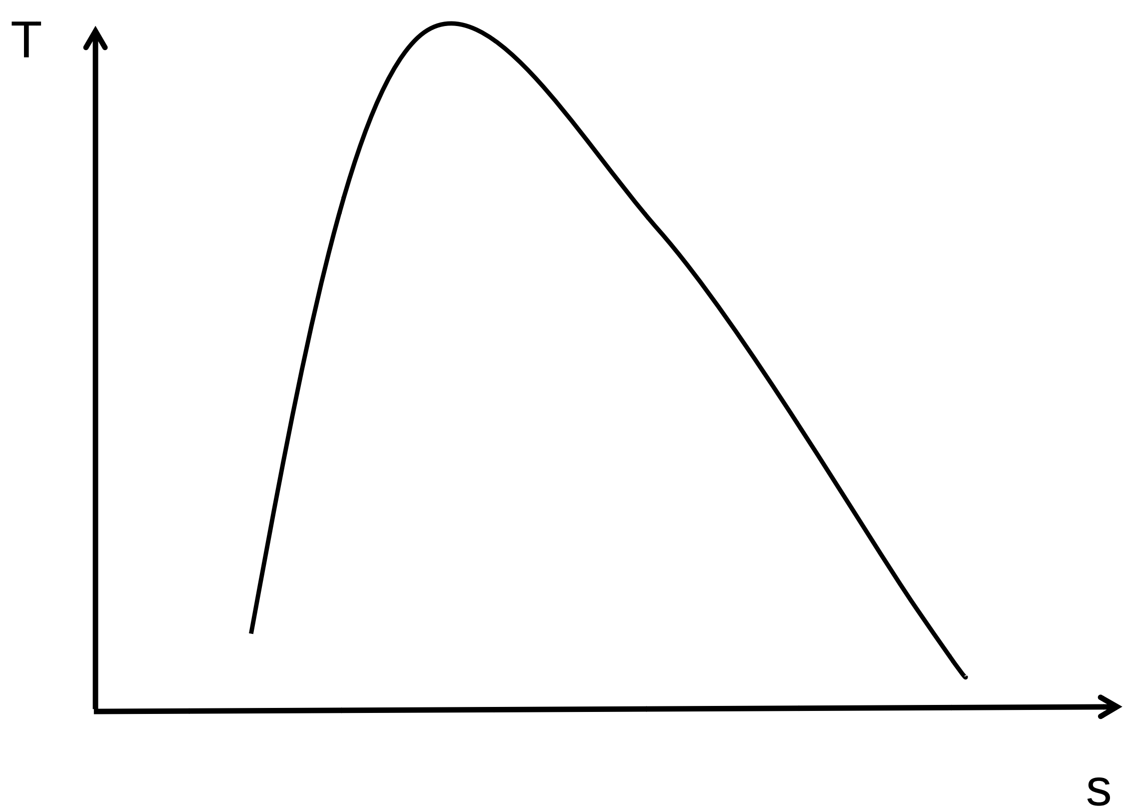
The thermal efficiency of this cycle is then

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{253.6}{582.5} = \mathbf{0.565}$$

alternately: $\eta_{th} = 1 - \frac{1}{r^{k-1}} = 1 - \frac{1}{8^{0.4}} = 0.565$

4. A steam Rankine cycle operates between the pressure limits of 2500 psia and 1 psia. The turbine inlet temperature is 800 °F. Assume pump is isentropic. The turbine isentropic efficiency is 90%.

- Sketch the cycle on the T-s diagram below.
- Define labels as follows:
  - state 1 is pump inlet
  - state 2 is pump outlet
  - state 3 is turbine inlet
  - state 4 is turbine outlet (***assume state 4 is two phase***)
  - state 4s is isentropic turbine outlet
- Label the four processes: heat rejection, turbine, pump, heat addition.
- Label pressures at all five states: P_1, P_2, P_3, P_4, P_{4s}
- Label the values in °F for temperatures: T_1, T_3, T_4, T_{4s}.



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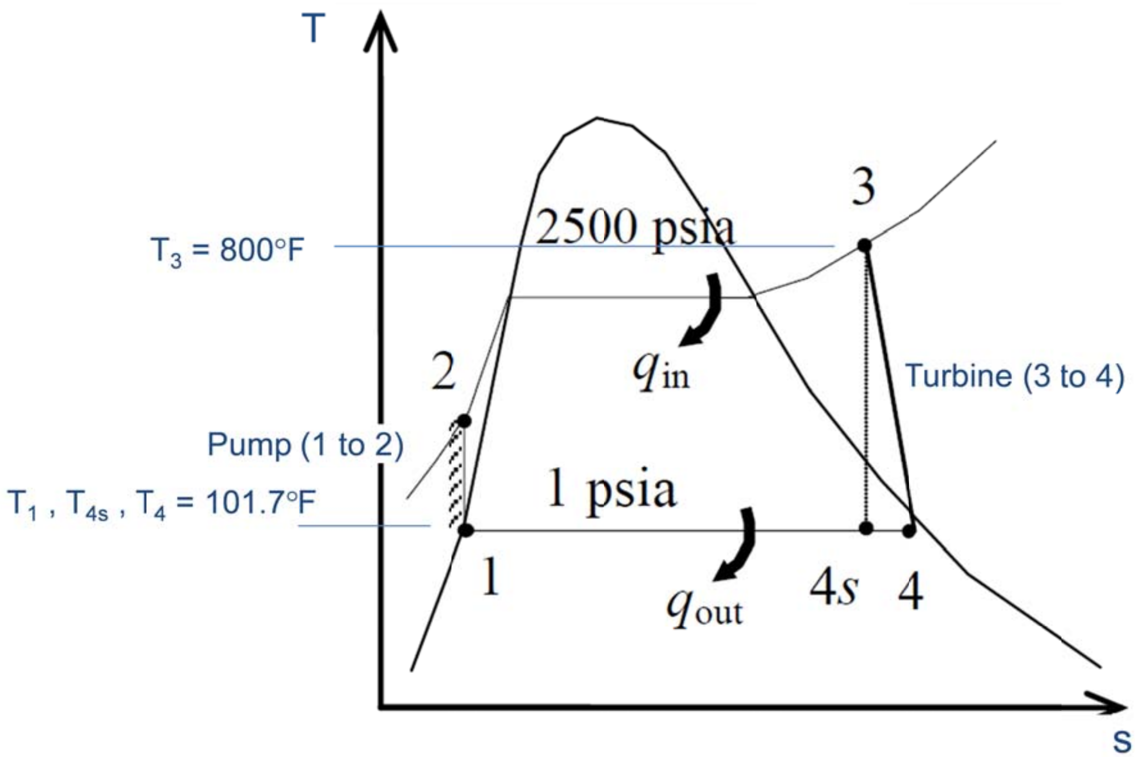
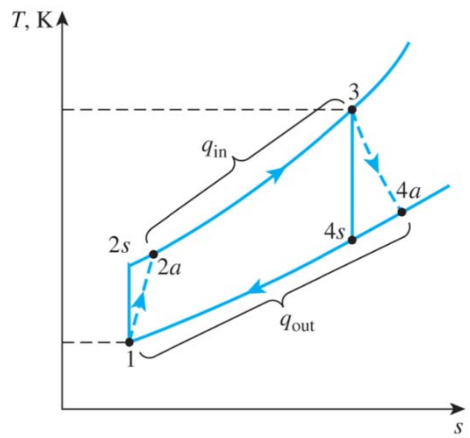
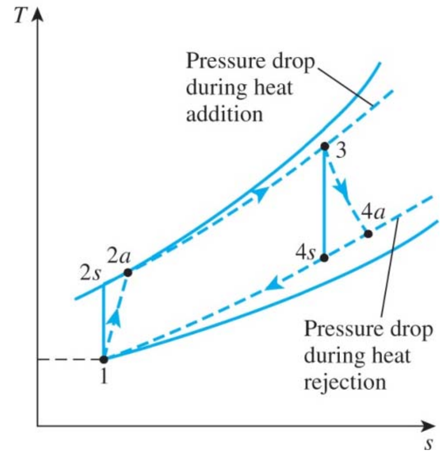


$P_1 = P_4 = P_{4s} = 1$ psia
$P_2 = P_3 = 2500$ psia

5. A simple Brayton cycle (diagrams below) uses air as the working fluid with a pressure ratio of 9.688. T_1 = 295 K and T_3 = 1240 K. The compressor isentropic efficiency is 83%. Determine the enthalpy, h_{2a} (kJ/kg).

   Neglect Δke and Δpe. Air standard assumptions apply. Assume an ideal gas with variable specific heats.





adapted from CCT 9-70

Air Properties from Table A-21 provided

Process 1 to 2s is isentropic

$$T_1 = 295\text{ K} \xrightarrow[\text{A-21}]{\text{Table}} \begin{cases} h_1 = 295.17 \text{ kJ/kg} \\ P_{r_1} = 1.3068 \end{cases}$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (9.688)(1.3068) = 12.66$$

$$\text{Table A-21 @ } P_r = 12.66 \begin{cases} h_{2s} = 565.17 \frac{\text{kJ}}{\text{kg}} \\ T_{2s} = 560\text{ K} \end{cases}$$

$$\eta_c = \frac{h_{2s} - h_1}{h_{2a} - h_1} \Rightarrow h_{2a} = h_1 + \frac{h_{2s} - h_1}{\eta_c}$$

$$h_{2a} = 295.17 + \frac{(565.17 - 295.17)}{0.83}$$

$$h_{2a} = 620.47 \text{ kJ/kg}$$

or $\boxed{620 \text{ kJ/kg}}$