ME 40

Thermodynamics

Spring 2009

Quiz #3

March 16, 2009

Name:____________________________________

SID: ____________________________________

Instructions:

Read each question carefully. Take into consideration the point values for each question. **Write your name and SID on each page**. You have roughly 45 minutes.

One double-sided reference sheet is permitted.

Good luck!

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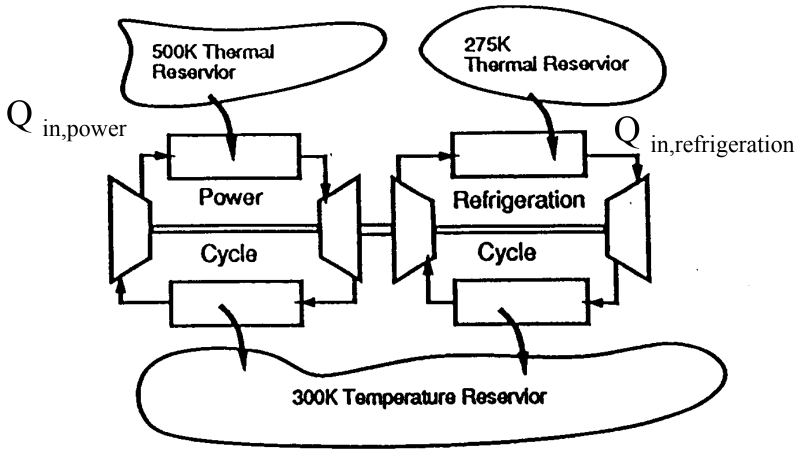
Question 1: [10 points]

Consider a device consisting of two cycles as sketched below. The heat engine cycle (the power cycle) operates between two thermal reservoirs at 500 K and 300 K respectively. The refrigeration cycle interacts with reservoirs at 300 K and 275 K respectively. The power from the heat engine cycle is used entirely to run the refrigeration cycle. Both cycles are assumed to be ideal Carnot cycles. Determine the ratio of heat inputs into these two cycles, $Q_{in,\,refrigeration}/Q_{in,\,power}$



solution:

The work from Carnot cycle W_{engine}=(1-300/500) $Q_{in,power}$=0.4 $Q_{in,power}$

Work required from the Carnot refrigeration cycle= $Q_{in,refrigeration}$/COP Carnot

where COP Carnot= 1/(300/275-1)= 11

Work required from the Carnot refrigeration cycle= $Q_{in,refrigeration}$ /11

Setting Work required from the Carnot refrigeration cycle= W_{engine}

$$Q_{in,refrigeration}/11= 0.4\ Q_{in,power}$$

$$Q_{in,refrigeration}/\ Q_{in,power}=4.4$$

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Question 2: [5 points]

An ideal gas initially at 300 K and 500 kPa (State 1) passes through an *adiabtic* throttling device. The pressure of this ideal gas drops to 100 kPa (State 2). Determine 1) the change of entropy per unit mass of this ideal gas (2 points), and 2) the minimum work required to reverse the throttling process from State 2 to State 1 (3 points). The gas constant of this ideal gas is R=0.3 kJ/kg-K.

1^{st} law gives $T_2=T_1$ as $h_2=h_1$.
Second law: the entropy change for an ideal gas is
$\Delta s= Cp \ln(T_2/T_1) - R \ln (P_2/P_1)= -R \ln (P_2/P_1)= -0.3$ kJ/kg-K ln (0.2)=0.48 kJ/kg-K
The minimum work required is equal to the loss of potential work= $T^*\Delta s$= 300 K * 0.48 kJ/kg-K = 144 kJ/kg. Alternatively, one can compute the reversible work for an isothermal compression process from State 2 to State 1: wrev= TR ln(P1/P2) =144 kJ/kg.

Question 3: [5 points]

An inventor claims that a new refrigeration compressor has been designed to receive saturated R-134a vapor at –20ºC (entropy of this vapor is s_g=0.9456 kJ/kg-K) and delivers superheated vapor at 0.7 MPa, 30ºC (entropy s_{super}=0.9313 kJ/Kg-K). The compression process has a net heat *loss* of 5kJ/kg to the surroundings at 300 K. Perform a steady-flow analysis to determine if the compression process violates the second law?

For steady-flow process, we have

$s_{gen}= s_{out} - s_{in} - q/T= 0.9313 - 0.9456 + 5/300= 0.002367$ kJ/kg-K >0; no violation of second law.

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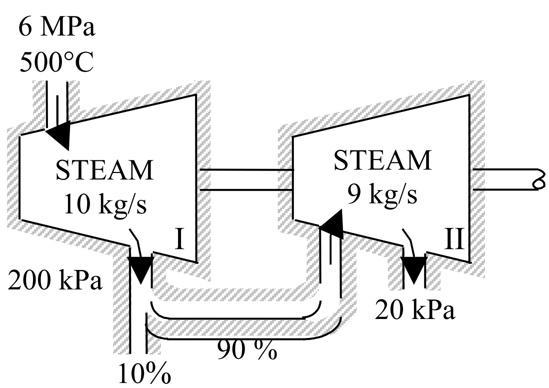
Question 4: [10 points]

Steam at 6 MPa and 500ºC enters a two-stage *adiabatic* turbine at a rate of 10 kg/s. Ten percent of the steam (mass flow rate =1 kg/s) is extracted at the end of the first stage at a pressure of 200 kPa. The remainder (mass flow rate =9 kg/s) is further expanded in the second stage and leaves turbine at 20 kPa. Determine the ***maximum possible*** power output of this turbine (sum of 1st and 2nd stages). Note: properties of steam at 6 MPa and 500ºC: v=0.05667 m^3/kg, u=3083.1 kJ/kg, h=3423.1 kJ/kg, s=6.8826 kJ/kg-K.

Solution: exit stage I: s=6.8826 = s_f+ x s_{fg}= 1.5302+ x * 5.596 → x=0.9565
h_1=504.71 + x * 2201.6 =2610.47 kJ/kg
power produced in the first stage = 1 kg/s (h_{inlet}-h_1)kj/kg= 812.63 kw
second stage: s=6.8826= 0.832+ x * 7.0752→ x=0.8552
h_2= 251.42 +x *2357.5 =2267.5kJ/kg
power from stage II = 9 kg/s (h_{inlet}- h_2) kJ/kg= 9 x (3423.1 – 2267.5) =10400.24 kw
total = 11,212.88 kw



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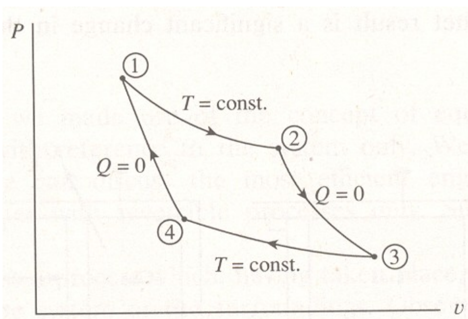
Question 5: [10 points]

A Carnot engine operating on **air** accepts 50 kJ/kg of heat from a high temperature reservoir at T_H and rejects 20 kJ/kg to a low temperature reservoir at T_L as sketched below. The pressure after isothermal expansion is 200 kPa (State 2) and the specific volume at State 3 is 10 m^3/kg.

1) Determine the temperature ratio of high temperature and low temperature reservoirs, T_H/T_L [2 points].
2) Determine the pressure at State 3. [5 points]
3) Determine T_H and T_L. [3 points]

Note: isentropic (adiabatic & reversible) compression and expansion processes satisfy the relationship Pv^k = constant. For air, k=1.4, and R_{air} = 0.287 kJ/kg·K and we will assume ideal gas law for air: $Pv=R_{air}\,T$.



P-v diagram for Carnot engine

1→2: Isothermal expansion

2→3: Adiabatic & reversible expansion

3→4: Isothermal compression

4→1: Adiabatic & reversible compression

1) The temperature reservoir ratio is T_H/T_L= 50/20=2.5.

2) Using the isentropic relation

$$P_3v_3^k= P_2v_2^k$$

and the ideal gas law we have $(T_2/T_3)=(P_2/P_3)^{(k-1)/k}$

Note that the reservoir temperature T_H is the same as T_2 as this is a reversible heat transfer so that $(T_2/T_3)=(T_H/T_L)=2.5$

→P_3=8.1 kPa

3) Using ideal gas law $P_3\, v_3$=Rair T_3→ $T_L=T_3= P_3\, v_3/R_{air}$=(8.1* 10)/0.287=282 K

T_H= 2.5 * T_L= 705.2 K