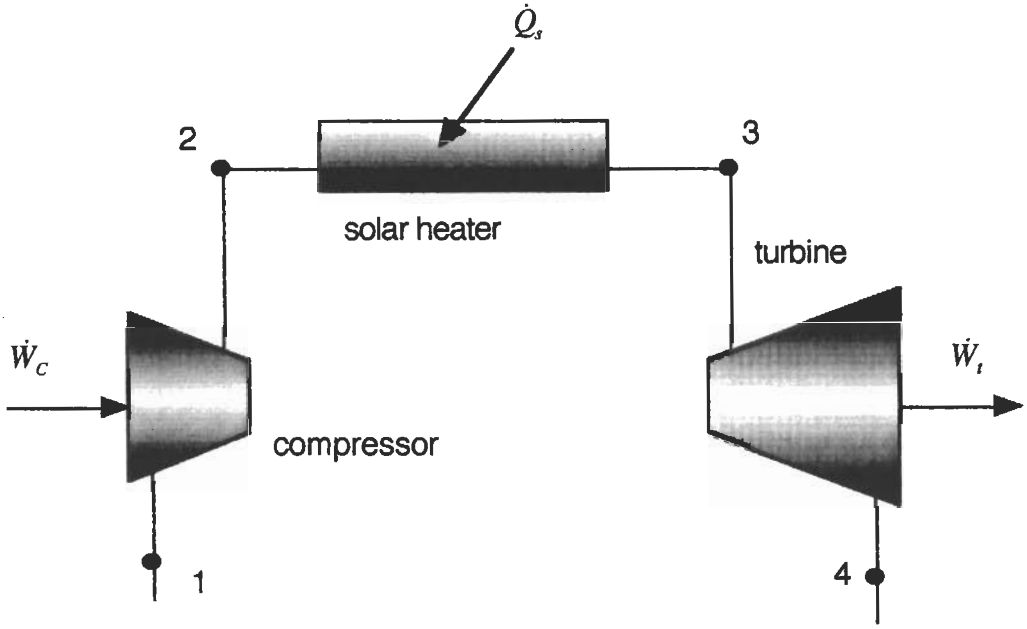
Mechanical Engineering Department
University of California at Berkeley

ME105B, Fall 2005
Prof. V. Carey

Midterm I **Name** w/soln

Instructions: Do both problems. Show all work and make sure that your final answers are clearly distinguishable *with proper units.*

1. (50 points)



Steam enters the compressor shown in the schematic above at state 1 with P_1 = 100 kPa and T_1 = 250 °C. The steam flow rate is 1.2 kg/s. The compressor operates reversibly and adiabatically. The exit pressure for the compressor is P_2 = 500 kPa. The steam then enters a solar heater that transfers heat into the steam flow at a rate of 1389 kW. The pressure drops to 400 kPa at the exit (3) of the heater. The pressure at the turbine exit (P_4) is 100 kPa.

(a) Determine the power input into the compressor.

(b) Determine the specific enthalpy at state 3.

(c) Assuming the turbine operates reversibly and adiabatically, find the power output of the turbine.

(d) Determine the turbine work output and estimate the exit temperature if the turbine is adiabatic with an efficiency of 0.8.

(a) $h_1 = 2974.5$ kJ/kg $s_2 = s_1 = 8.0346$, $P_2 = 500$ kPa $\rightarrow$ $\{ T_2 = 500\,°C,\ h_2 = 3484.5 \}$

$s_1 = 8.0346$ kJ/kgK

$\dot{W}_c = \dot{m}(h_2 - h_1) = 1.2(3484.5 - 2974.5) = \underline{612 \text{ kW}}$

(b) $h_3 = h_2 + \frac{\dot{Q}_s}{\dot{m}} = 3484.5 + \frac{1389}{1.2} = \underline{4642}$ kJ/kg $\Big\}$ $T_3 = 1000°C$

$P_3 = 400$ kPa $\qquad s_3 = 9.3396$

(c) $\dot{W}_{t,s} = \dot{m}(h_3 - h_{4s})$

$s_{4s} = s_3 = 9.3396$
$P_{4s} = 100$ kPa $\Big\}$ $h_{4s} = 3929.4$

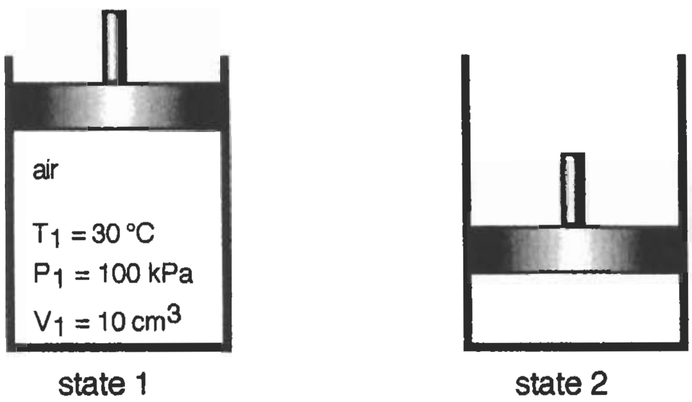
$\dot{W}_{t,s} = 1.2(4642 - 3929) = \underline{855.6}$ kW

(d) $\dot{W}_t = 0.8(855.6) = \underline{684.5}$ kW

$h_4 = h_3 - \frac{\dot{W}_t}{\dot{m}} = 4642 - \frac{684.5}{1.2} = 4072$ kJ/kg

$P_4 = 100$ kPa

$\Rightarrow T_4 = 700 + \frac{4072 - 3929}{4160 - 3929}(800 - 700) = \underline{762}$ °C



2. (50 points) In analyzing this system, treat the air as an ideal gas with constant specific heats.

The piston and cylinder device above contains air. Initially (state 1) the air inside is at a pressure of 100 kPa, the temperature is 30 °C and the system volume is 10 cm^3. The gas is then compressed to state 2 reversibly and isothermally. The volume in state 2 is 1.5 cm^3.

a. Determine the pressure in state 2
b. Determine the work done compressing the gas from state 1 to state2
c. Determine the change in entropy for the system from state 1 to state 2
d. Determine the heat transfer for the process from state 1 to state 2.

e. An inventor claims to have deigned a device that compresses air adiabatically from state 1 above to a final state f in which P_f = 500kPa and T_f = 200 °C. Is such a device possible? Justify your answer.

$$m = \frac{P_1 V_1}{R T_1} \quad \frac{100{,}000\,(10^{-5})}{.287(1000)\,(303)}$$

$$= 1.15 \times 10^{-5}\ kg$$

air
$c_p = 1.005\ kJ/kg\,K$
$c_v = 0.718$
$R = 0.287$
$k = 1.400$

(a) $P_2 = \frac{V_1}{V_2} P_1$ (for isothermal)

$$\Rightarrow P_2 = \left(\frac{10}{1.5}\right) 100 = \underline{666.7\ kPa}$$

(b) $W = \int_1^2 P\,dV = \int_1^2 \frac{mRT}{V}\,dV = mRT \ln(V_2/V_1)$

$$= (1.15 \times 10^{-5})(.287)(1000)(303) \ln(1.5/10) = \underline{1.897\ J}$$

(c) $S_2 - S_1 = m(s_2 - s_1) = m c_v \ln(T_2/T_1) + m R \ln(v_2/v_1)$

$= 1.15\times10^{-5}(.287)\ln(1.5/10) = -6.26\times10^{-6}\ kJ/K$

(d) $\Delta U = 0$ since $\Delta T = 0$ so

$\Delta U = 0 = Q - W \rightarrow Q = W = -1.897\ J$

(e) 1^{ST} Law requires $\Delta U = -W$

$\rightarrow W = -\Delta U = -m c_v (T_f - T_1)$

$= -1.15\times10^{-5}(.718)(200-30) = -1.40\times10^{-3}\ kJ$

this is ok.

2^{nd} Law Requires $dS \geq \frac{\delta Q}{T} \rightarrow dS \geq 0 \rightarrow S_2 - S_1 \geq 0$

$S_2 - S_1 = m c_p \ln(T_2/T_1) - m R \ln(P_2/P_1)$

$= 1.15\times10^{-5}(1.005)\ln(473/303) - 1.15\times10^{-5}(.287)\ln(500/100)$

$= -1.64\times10^{-7}\ kJ/K$

this violates the 2^{nd} Law $\rightarrow$ impossible