UNIVERSITY OF CALIFORNIA
Mechanical Engineering
Prof. C.Fernandez-Pello

ME40/Fall 2009

NAME SOLUTION.

This examination is open book and open notes. Please write your name in the space provided above.

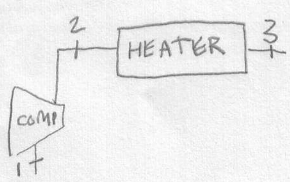
MIDTERM EXAMINATION #2 (11/6/2009)

Question 1 (50pts):

Hot air at high pressure is used to remove moisture from ceramic molds in an industrial process. The drying air comes from the following process. **Air** at 100 kPa and 350 K enters an adiabatic compressor at a rate of 1 kg/s. At the compressor outlet the pressure is 400 kPa. The compressor efficiency is 85%. The air then enters a heater where 120 kW of heat is added at constant pressure.

a) How much power does the compressor require? (15 pts)
b) What is T at the compressor outlet? (10 pts)
c) What is the change in entropy between the compressor inlet and outlet? (10 pts)
d) What are T, and P at the heater outlet? (10 pts)

LIST YOUR ASSUMPTIONS (5 pts)



STATE 1: $P_1 = 100\,kPa$ $T_1 = 350\,K$ $\dot{m} = 1\,kg/s$
STATE 2: $P_2 = 400\,kPa$
STATE 3: $P_3 = P_2 = 400\,kPa$

COMPRESSOR:

PROCESS: $\dot{Q} = 0$ $\Delta KE = \Delta PE \approx 0$

$\eta = 0.85$

$\eta = \frac{\dot{W}_S}{\dot{W}_A}$ $\dot{W}_A = \frac{\dot{W}_S}{\eta}$ $\dot{W}_S = \dot{m}(h_{2S} - h_1)$

ASSUME; IDEAL GAS, CONSTANT SPECIFIC HEAT

$\dot{W}_A = \left(\frac{1}{\eta}\right)\dot{m}\, c_p (T_{2S} - T_1)$

$T_{2S} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$, $k = 1.4$ $c_p = 1 \frac{kJ}{kg \cdot K}$

$\dot{W}_A = \left(\frac{1}{\eta}\right)\dot{m}\, c_p \left(T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - T_1\right) = \boxed{200\ kW}$

Question 1 (extra work space):

$\dot{W}_A = \dot{m} c_p (T_2 - T_1)$

$T_2 = \frac{\dot{W}_A}{\dot{m} c_p} + T_1$

$T_2 = 550.\ K$

$s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R \ln\frac{P_2}{P_1}$ $\quad R_{AIR} = 0.287 \frac{kJ}{kg\,K}$

$s_2 - s_1 = \ln\left(\frac{550.6}{350}\right) - 0.287 \ln(4)$

$\Delta s = 0.054 \frac{kJ}{kg\,K}$

HEATER:

$\dot{Q} = 120\ kW$

$\dot{Q} = \dot{m} c_p (T_3 - T_2) = \dot{m}(h_3 - h_2)$

$T_3 = 670\ K \quad P_3 = 400\ kPa$

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LIST YOUR ASSUMPTIONS (5 pts)

FOR A-17 METHOD.

USING

$s_2 - s_1 = s_2^o - s_1^o - R\ln\frac{P_2}{P_1}$

@1. $h_1 = 350.49 \frac{kJ}{kg}$ $s_1^o = 1.85708\ kJ/kgK$

FOR ISENTROPIC CASE.

$s_{2s} = s_1$ $s_2^o = s_1^o + R\ln\left(\frac{P_2}{P_1}\right)$

$s_2^o = 1.85708 + 0.287\ln(4)$

$s_2^o = 2.2549$

@2s $h_{2s} = 523 \frac{kJ}{kgK}$ ~~$T_{2s} = 520\ K$~~

$\dot{W}_s = \dot{m}(h_{2s} - h_1) = 172.5\ kW$

$\dot{W}_A = \frac{\dot{W}_s}{\eta} = \boxed{202.9\ kW}$

Question 1 (extra work space):

$\dot{W}_A = \dot{m}(h_2 - h_1)$

$h_2 = 553.4 \ \frac{kJ}{kg}$

$T_2 \approx 548 \ K$

$s_2^\circ = 2.318 \ \frac{kJ}{kg K}$

$s_2 - s_1 = s_2^\circ - s_1^\circ - R \ln\left(\frac{P_2}{P_1}\right)$

$s_2 - s_1 = 2.318 - 1.857 - 0.287 \ln(4)$

$s_2 - s_1 = 0.06 \ \frac{kJ}{kg K}$

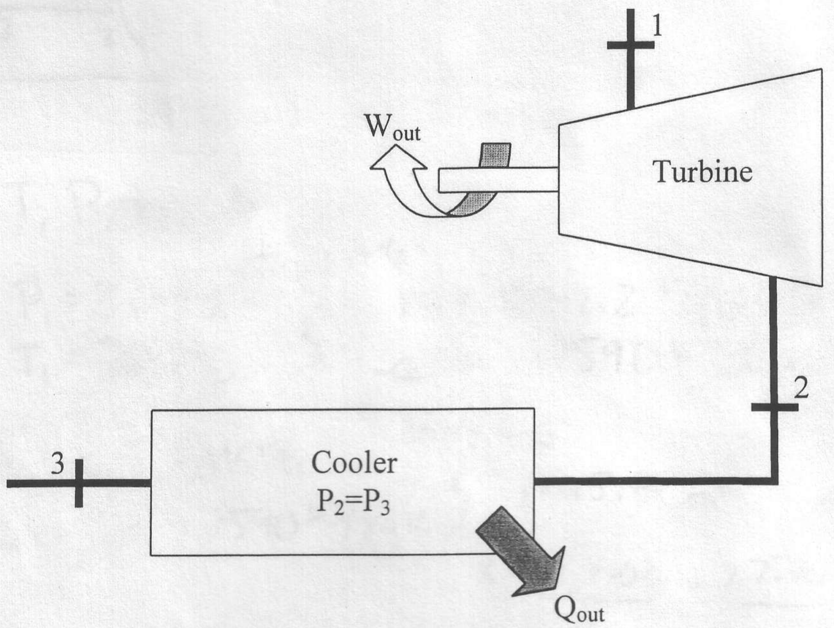
$\dot{Q}_{23} = \dot{m}(h_3 - h_2)$

$h_3 = 673.4 \ \frac{kJ}{kg}$

$T_3 \approx 663 \ K$ $P_3 = 400 kPa$

Question 2 (50 pts):

In a power plant, superheated **steam** (H_2O) entering a reversible adiabatic turbine has a pressure of 3MPa, 700C and a mass flow rate of 50 kg/s. The H_2O then travels to a cooler, where the heat is removed to preheat the steam entering a boiler. The saturated liquid leaving the condenser is at a pressure of 10 kPa.



a) Draw the T-s diagram for this process (10pts)

b) Find T, P, h, and s for the fluid entering the turbine (1), the fluid between the turbine and condenser (2) and the fluid leaving the condenser (3). Put your final answer is the box below. (10pts)

P_1 = 3 MPa	$P_2 = P_3$ = 10 kPa	P_3 = 10 kPa
T_1 = 700 °C	T_2 = 45.81 °C	T_3 = 45.81 °C
h_1 = 3912.2 kJ/kg	h_2 = 2459.52 kJ/kg	h_3 = 191.81 kJ/kg
s_1 = 7.7590 kJ/kgK	$s_2 = s_1$ = 7.7590 kJ/kgK	s_3 = 0.6492 kJ/kgK

c) Find the work produced by the turbine. (10pts)

d) Find the heat removed by the cooler. (10pts)

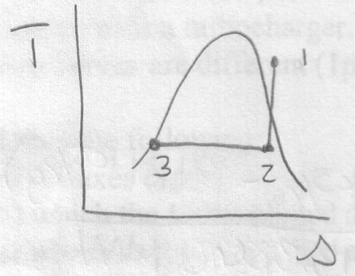
-1 for each one wrong
Do not remove points for incorrect values from pt (b)

e) What effect would lowering the condenser's pressure have on the turbine's work output? Would it increase, decrease or stay the same? Explain your answer. (10pts)

any use of ideal gas results in 0 for the part.

Question 2 (extra work space):

a)



b) Find T, P, h, s

state 1: $P_1 = 3\text{MPa}$, $T_1 = 700°C$ } table A-6 $h_1 = 3912.2 \text{ kJ/kg}$, $s_1 = 7.7590 \text{ kJ/kg}$

state 2: $P_2 = P_3 = 10\text{kPa}$, $s_2 = s_1 = 7.7590 \text{ kJ/kgK}$ } table A-5 $T_2 = 45.81°C$

$$x = \frac{s_2 - s_f}{s_{fg}} = \frac{7.7590 \text{ kJ/kgK} - .6492 \text{ kJ/kgK}}{7.4996 \text{ kJ/kgK}}$$

$x = .948$

$h_2 = h_f + xh_{fg} = 191.81 \text{ kJ/kg} + (.948)(2392.1 \text{ kJ/kg})$

$h_2 = 2459.52 \text{ kJ/kg}$

state 3: $P_3 = 10\text{kPa}$, $x = 0$ } table A-5 $T_3 = 45.81°C$, $h_3 = 191.81 \text{ kJ/kg}$, $s_3 = 0.6492 \text{ kJ/kgK}$

c) Find $\dot{W}_T$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{in}^{\to 0} + \dot{W}_{in}^{\to 0} + \dot{m}(h_1 + \frac{V_1^2}{2}^{\to 0} + gz_1^{0}) = \dot{Q}_{out}^{\to 0} + \dot{W}_{out} + \dot{m}(h_2 + \frac{V_2^2}{2}^{\to 0} + gz_2^{0})$$

$$\dot{m}h_1 = \dot{W}_{out} + \dot{m}h_2$$

$$\dot{W}_{out} = \dot{m}(h_1 - h_2)$$

$$\dot{W}_{out} = (50 \text{ kg/s})(3912.2 \text{ kJ/kg} - 2459.52 \text{ kJ/kg})$$

$\dot{W}_{out} = 72634 \text{ kW} = 72.634 \text{ MW}$

d) Find $\dot{Q}_c$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{Q}_{in}^{\nearrow 0} + \dot{W}_{in}^{\nearrow 0} + \dot{m}\left(h_2 + \frac{V_2^2}{2}^{\nearrow 0} + g z_2^{\nearrow 0}\right) = \dot{Q}_{out} + \dot{W}_{out}^{\nearrow 0} + \dot{m}\left(h_3 + \frac{V_3^2}{2}^{\nearrow 0} + g z_3^{\nearrow 0}\right)$$

$$\dot{m} h_2 = \dot{Q}_{out} + \dot{m} h_3$$

$$\dot{Q}_{out} = \dot{m}(h_2 - h_3)$$

$$\dot{Q}_{out} = 50\ kg/s\,(2459.52\ kJ/kg - 191.81\ kJ/kg)$$

$$\boxed{\dot{Q}_{out} = 113386\ kW = 113.386\ MW}$$

e) The work would increase because a lower pressure would relate to a lower enthalpy. This would increase the difference between h_{in} and h_{out} in the equation $\dot{W}_{out} = \dot{m}(h_{in} - h_{out})$

alternative d)

$$\Delta s = \dot{m}\frac{Q}{T} \rightarrow \text{since } T = \text{const} \rightarrow \dot{Q} = \dot{m}T(s_3 - s_2)$$

$$\dot{Q} = (50\ kg/s)(45.81° + 273)(.6492 - 7.759$$

$$\boxed{\dot{Q} = -113.334\ MW}$$

Question 3 (5pts extra credit):

On the graph below, draw the P-v diagram for a normally aspirated engine and the same engine with a turbocharger. Draw them both on the same graph and describe why the two curves are different (1pt)

Label the following:
a) the axes (1pt)
b) which the turbocharged diagram and which the normally aspirated diagram (1pt)
c) where heat (Q) is added and where it is removed (1pt)
d) where the compression and expansion take place (1pt)