

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics

Spring 2007

Exam 1 – Part I, Version A - Open Book, closed notes, 2/20/07,
SUBMIT ALL ORIGINAL PAGES.

1. An ideal gas is compressed isothermally in a piston/cylinder from 0.1 MPa to 4 MPa. The cylinder contains 1.2 mol at 340 K. For the ideal gas, $C_p/R = 8.851$ is independent of T.

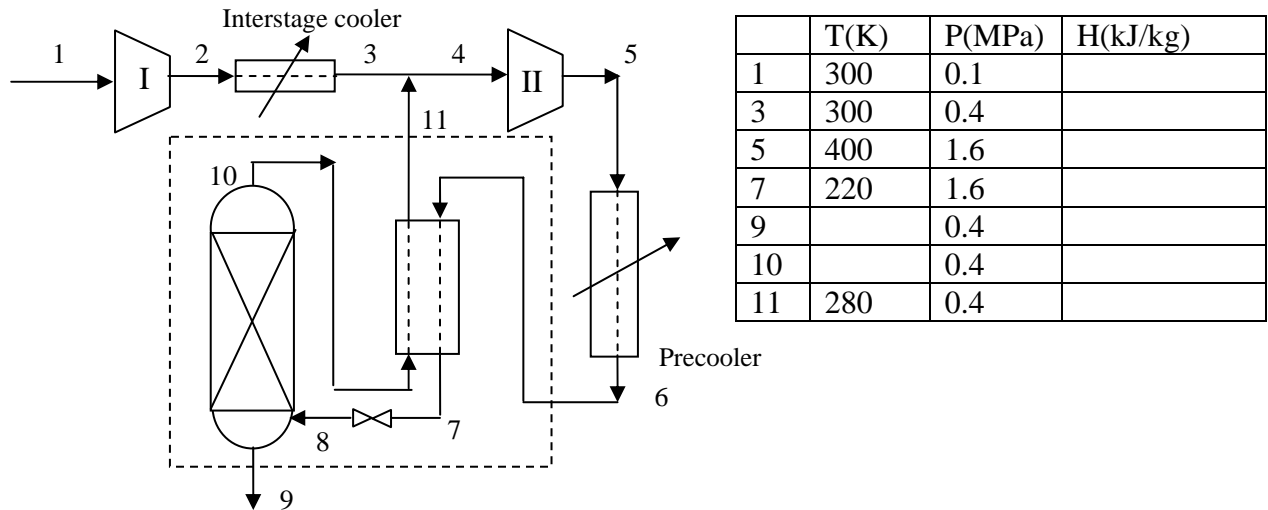
(a) (10) Determine the amount of work performed (kJ) and the reversible change in internal energy, ΔU (kJ) if the device is reversible.

(b) (5) What is the required heat transfer if the device in part (a) has an efficiency of 80%?

2. (10) A simple derivative manipulation is applied to each of the starting expressions in the left column below. Some of the manipulations may involve errors. Indicate whether the ending expression in each row is valid or invalid. Work that is shown in the scratch area may be helpful for partial credit.

Starting Expression	Ending Expression	Indicate Valid or Invalid
$\left(\frac{\partial S}{\partial P}\right)_V$	$\left(\frac{\partial S}{\partial P}\right)_V = \frac{-C_V}{T} \left(\frac{\partial T}{\partial P}\right)_V$	
$\left(\frac{\partial T}{\partial V}\right)_H$	$\left(\frac{\partial T}{\partial V}\right)_H = -\left(\frac{\partial T}{\partial H}\right)_V \left(\frac{\partial V}{\partial H}\right)_T$	
$\left(\frac{\partial A}{\partial T}\right)_P$	$\left(\frac{\partial A}{\partial T}\right)_P = C_P - P \left(\frac{\partial V}{\partial T}\right)_P$	

The next few questions involve the liquefaction processing of ethylene using the following flowsheet. A partial set of conditions is provided in the table. Mark the attached chart as you use it and SUBMIT it with your exam.



3. (10) Compressor I is 80% efficient. Find the work (kJ/h) required to compress 120 kg/h.

4. (10) H_9 is saturated liquid, H_{10} is saturated vapor, Find m_{10}/m_7 and m_9/m_7 .

5. (10) Use the dotted boundary to find H_6 . Note: if you were unable to find the answer for problem 4, and find it necessary, use $m_{10}/m_7 = 0.1$.

6. (5) Find the heat transfer necessary (kJ/kg) in the precooler.

Name _____

Ethylene Chart

Michigan State University

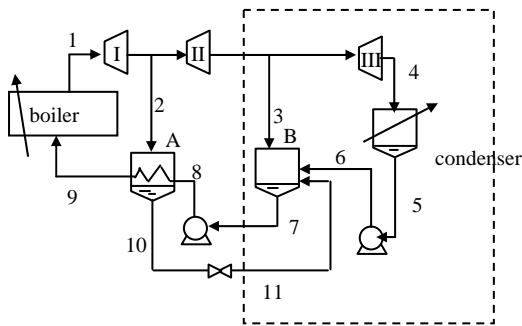
DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics

Spring 2007

Exam 1 – Part II, Open Book, closed notes, 2/20/07,
SUBMIT ALL ORIGINAL PAGES.

The next few problems consider the combined reheat and regenerative cycle shown below. Unit A is a closed feedwater preheater. Unit B is an open feedwater preheater. The turbines and pumps are adiabatic.



	P(MPa)	T(C)	H (kJ/kg)	S(kJ/kg-K)
1	2.5	500		
2	0.5	300	3064.6	
3	0.2	200	2870.7	
4	0.01			
6			192.1	
7			504.7	
11			640.1	

7. (5) How many unique flowrates exist in the process? _____
How many unique pressures? _____

8. (10) The mass flow ratio $m_2/m_1 = 0.035$. Find m_3/m_1 .

9. (10) Determine the enthalpy of stream 8. The pumps are 80% efficient.

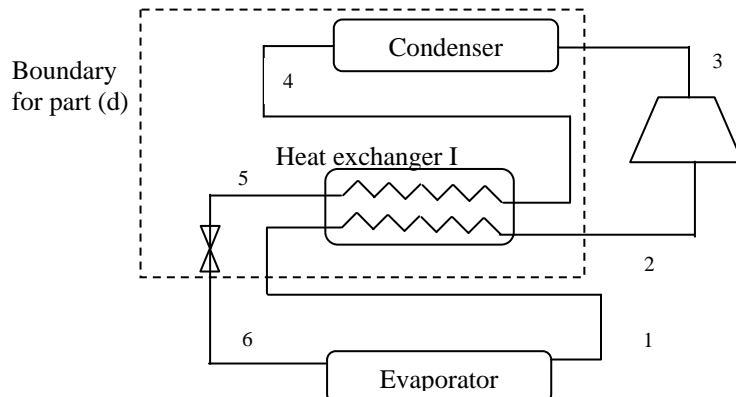
10. (10) If turbine III is 85% efficient, determine the work per kg of stream 4 flow.

12. (5) Write the energy balance for the boundary indicated by the dotted line. Use intensive fluid properties along with mass flowrates in your answer. For work, use $m_i W_S$ instead of \underline{W}_S ; the same applies for heat. Eliminate terms that are not relevant. You do not need to combine with other balances.

February 22, 2006, OPEN BOOK, CLOSED NOTES, PART I

General Instructions

- Submit all problems in the order of the exam.
 - Do all work on exam pages. Use back if necessary. Submit all exam pages
 - For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
 - Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.
1. An ideal gas flows through a steady-state adiabatic compressor ($\eta = 0.8$). The inlet is 298K and 0.1 MPa. The outlet is 0.4 MPa. The temperature-independent heat capacity is $C_p = 29.1$ J/molK.
 - (a) (10) Determine the reversible outlet temperature.
 - (b) (10) Determine the actual outlet temperature.
 - (c) (5) Determine the size of compressor (kW) necessary to process 150 mol/min.
 2. The refrigeration cycle below uses R-500 (PH diagram attached). Stream 1 is saturated vapor at 0.2 MPa and stream 4 is saturated liquid at 0.8 MPa. The compressor is adiabatic ($\eta = 0.85$). Heat exchanger I serves increase the temperature from 1 to 2 and decrease the temperature from 4 to 5. Stream 2 is at 280K and 0.2MPa.



A table is provided for convenience on pg 2. The problem may not require all values.

Stream	T(K)	P (MPa)	H(kJ/kg)	S(kJ/kg-K)
1		0.2		
2	280	0.2		
3'				
3				
4		0.8		
5				
6				

Mark your points clearly on the attached chart.

(a) (15) Determine the work done by the compressor (kJ/kg).

(b) (5) Determine the enthalpy of stream 5.

(c) (5) Determine the quality of stream 6 and the heat transfer in the evaporator (kJ/kg).
(Note: if you were unable to locate H5 in part (b), assume a value of 80 kJ/kg for this calculation).

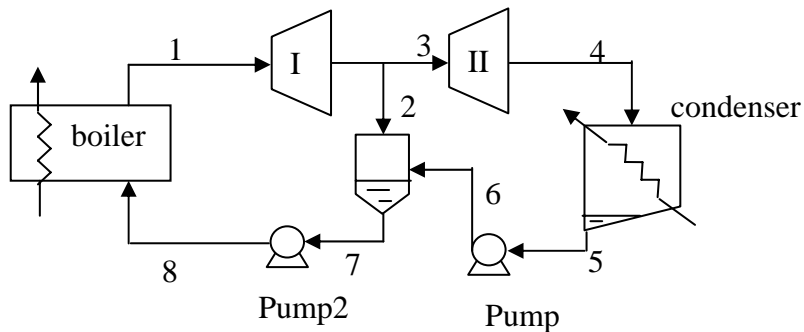
(d) (10) For the dotted boundary, write the energy balance for R-500. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q 's and W 's. Do not rearrange the balance or combine with other equations.

R-500 chart

February 22, 2006, OPEN BOOK, CLOSED NOTES, PART II

General Instructions

- Submit all problems in the order of the exam.
 - Do all work on exam pages. Use back if necessary. Submit all exam pages
 - For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
 - Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.
3. A power plant uses a two stage turbine with a open feedwater preheater as shown below. Steam exits the boiler/superheater at 500°C and 3 MPa. The outlet of the first adiabatic turbine ($\eta = 0.8$) is at 0.3 MPa. The outlet of the second adiabatic turbine ($\eta = 0.8$) is 0.01 MPa. Hint: you do not need to find states for all the streams. Solve for the streams as needed.



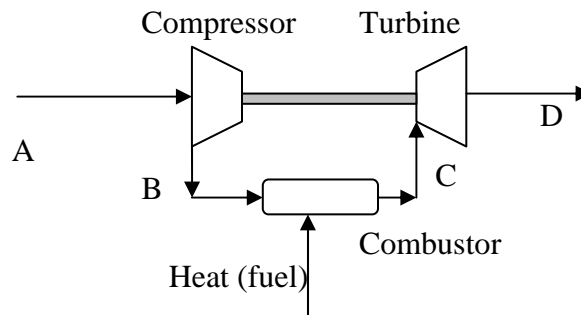
- (a) (10) Determine the reversible outlet enthalpy for turbine I. Note: if you interpolate using a calculator program, be sure to provide the values plugged in.

- (b) (5) Determine the actual outlet enthalpy from turbine I and work (kJ/kg) produced by turbine I.
- (c) (10) Determine the enthalpies of streams 5, 6, 7.
- (d) (10) Determine the ratio of flowrate ratio, m_2/m_1 .
- (e) (5) Determine the actual entropy for the outlet of turbine I. Note: if you interpolate using a calculator, be sure to provide the values plugged in.

February 24, 2005, OPEN BOOK, CLOSED NOTES

General Instructions

- Submit all problems in the order of the exam.
 - Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
 - For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
 - Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.
1. Methane (1.6 moles) is compressed in a closed piston/cylinder isothermally. The initial temperature and pressure are 253K and 0.1 MPa. The final pressure is 0.5 MPa. Assume $C_p/R = 4.298$ is independent of temperature.
- (a) (5) Determine the work required (kJ).
- (b) (5) Determine ΔH and Q .
- (c) (5) Determine ΔS (J/K).
2. An ideal gas is used in a gas turbine as shown below. The compressor ($\eta = 0.8$) and the turbine ($\eta = 0.8$) are coupled through a shaft. The gas turbine is to be modeled as a Brayton cycle (ignoring moles of fuel and combustion products). $T_A = 25^\circ\text{C}$, $P_A = P_D = 1$ bar. The pressure at B and C is 7 bar. The temperature at C is 845°C . For the ideal gas, use $C_p = 29.1$ J/mol-K, and assume C_p is independent of T.

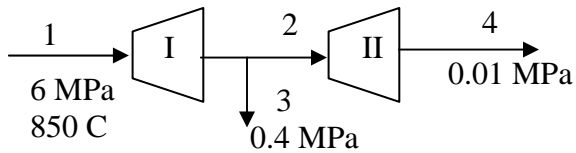


(a) (5) Determine the work required in the compressor (kJ/mol) and the outlet temperature B.

(b) (5) Determine the work produced by the turbine (kJ/mol).

(c) (5) Determine the amount of heat that must be added to the combustor by burning fuel. (kJ/mol).

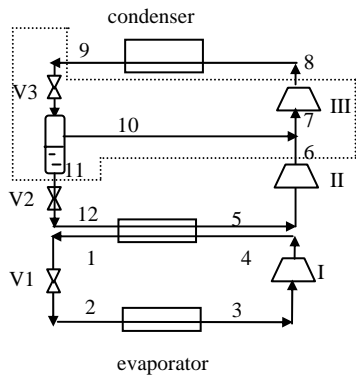
3. Adiabatic steam turbines I and II are each 85% efficient. Determine the work produced in each turbine (kJ/kg). Provide the numbers used for any interpolation.



(a) (15) Determine the outlet state 2 and the work produced by the turbine I.

(b) (10) Determine the outlet state 4 and the work produced by the turbine II.

4. The following cascade cycle uses ethane. The compressors are adiabatic and 75% efficient. The operating fluid is ethane (chart attached). The dotted line is a boundary used in part (e).



	P(MPa)	T(K)	H (kJ/kg)	S(kJ/kg-K)
1				
2	0.5	220		
3	0.5			
4'	1.2			
4	1.2			
5	1	240		
6'				
6				
7				
8	3.5			
8'	3.5			
9				
10	2			
11	2			
12	1			

- (a) (10) Determine the enthalpies for states 9, 11, 1. Label the states on the PH chart.
- (b) (10) Determine the flowrate ratio m_{10}/m_9 .
- (c) (10) Mark states 2 and 3 on the chart. Determine the cooling provided by the evaporator, kJ/kg.
- (d) (10) Mark state 4' on the chart. Determine the work required in compressor I if has a mechanical efficiency of 85%.
- (e) (10) For the dotted boundary, write the energy balance for ethane. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q's and W's. Do not rearrange the balance or combine with other equations.

Ethane chart

February 22, 2004, OPEN BOOK, CLOSED NOTES

General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

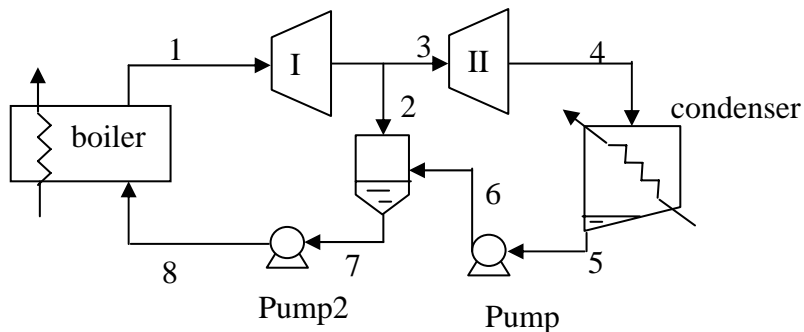
1. An ideal gas flows through a steady-state adiabatic compressor ($\eta = 0.8$). The inlet is 298K and 0.1 MPa. The outlet is 0.4 MPa. The temperature-independent heat capacity is $C_p = 29.1$ J/molK.

(a) (10) Determine the reversible outlet temperature.

(b) (10) Determine the actual outlet temperature.

(c) (5) Determine the size of compressor (kW) necessary to process 150 mol/min.

2. A power plant uses a two stage turbine with a open feedwater preheater as shown below. Steam exits the boiler/superheater at 500°C and 3 MPa. The outlet of the first adiabatic turbine ($\eta = 0.8$) is at 0.3 MPa. The outlet of the second adiabatic turbine ($\eta = 0.8$) is 0.01 MPa. Hint: you do not need to find states for all the streams. Solve for the streams as needed.



- (a) (10) Determine the reversible outlet enthalpy for turbine I. Note: if you interpolate using a calculator program, be sure to provide the values plugged in.
- (b) (5) Determine the actual outlet enthalpy from turbine I and work (kJ/kg) produced by turbine I.
- (c) (10) Determine the enthalpies of streams 5, 6, 7.
- (d) (10) Determine the ratio of flowrate ratio, m_2/m_1 .
- (e) (5) Determine the actual entropy for the outlet of turbine I. Note: if you interpolate using a calculator, be sure to provide the values plugged in.

3. The refrigeration cycle below uses R-500 (PH diagram attached). Stream 1 is saturated vapor at 0.2 MPa and stream 4 is saturated liquid at 0.8 MPa. The compressor is adiabatic ($\eta = 0.85$). Heat exchanger I serves increase the temperature from 1 to 2 and decrease the temperature from 4 to 5. Stream 2 is at 280K and 0.2MPa.

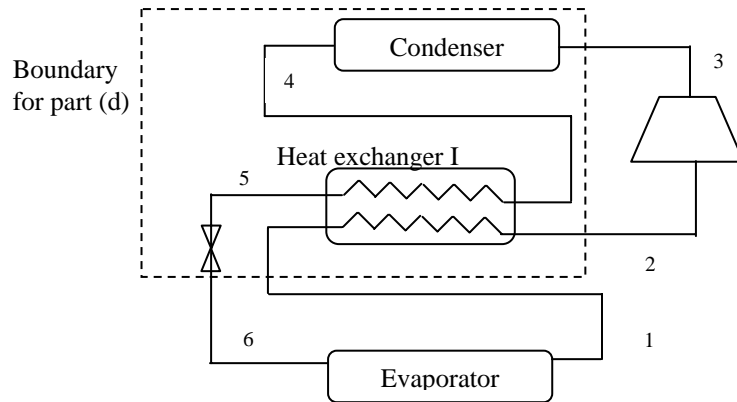


Table is provided for convenience. The problem may not require all values.

Mark your points clearly on the attached chart.

Stream	T(K)	P (MPa)	H(kJ/kg)	S(kJ/kg-K)
1		0.2		
2	280	0.2		
3'				
3				
4		0.8		
5				
6				

(a) (15) Determine the work done by the compressor (kJ/kg).

(b) (5) Determine the enthalpy of stream 5.

(c) (5) Determine the quality of stream 6 and the heat transfer in the evaporator (kJ/kg).
(Note: if you were unable to locate H5 in part (b), assume a value of 80 kJ/kg for this calculation).

(d) (10) For the dotted boundary, write the energy balance for R-500. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q's and W's. Do not rearrange the balance or combine with other equations.

R-500 chart

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics

Spring 2003

Exam 1 - Open Book, closed notes, 2/20/03, SUBMIT ALL ORIGINAL PAGES.

1. A piston/cylinder containing 1.5 mole of methane is initially at 400K and 5 MPa. For this initial state, determine the total heat transfer (J), total work (J), and change of internal energy (J) associated with following the specified reversible pathways to the specified final state.

Data: $C_p = 35.73 \text{ J/mol-K}$, independent of T.

(a) (10) Initially at 400K and 5 MPa, cooled at constant pressure to 220 K.

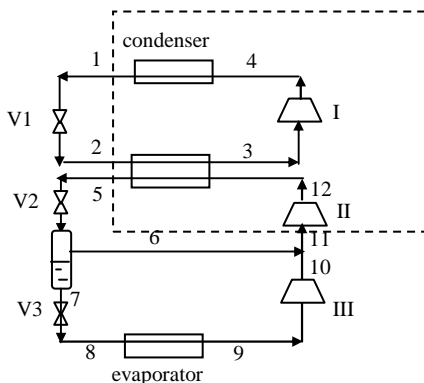
(b) (10) Initially at 400K and 5 MPa, cooled at constant volume to 220 K.

(c) (10) Initially at 400K and 5 MPa, expanded adiabatically and reversibly to twice the volume.

The next few problems consider the cascade refrigeration cycles shown below. The compressors are adiabatic and 75% efficient. The operating fluid is refrigerant 22 (chart attached).

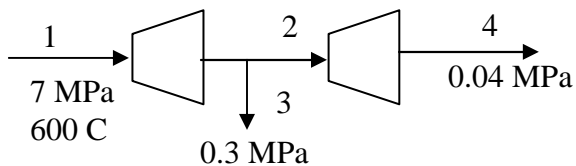
MARK YOUR ANSWERS CLEARLY ON THE CHART AND SUBMIT WITH YOUR WORK.

The dotted line is a boundary used in problem 5.



	P(MPa)	T(K)	H (kJ/kg)	S(kJ/kg-K)
1		340		
2	1			
3				
4'				
4				
5	1.4			
6	0.31	260		
7	0.31	260		
8	0.14			
9	0.14		270	
10'				
10				
11			290	
12'				
12			343.5	

2. (10) Find H_{10} , mark it on the plot and label it.
3. (10) Locate state 5 on the graph and mark the point clearly. Find q out of valve V2, and determine the flowrate of m_6 and m_8 if $m_5 = 50$ kmol/h.
4. (20) find H_6 and verify that $H_{11} = 290$ kJ/kg.
5. (10) For the dotted boundary, write the energy balance for refrigerant 22. All compressors are adiabatic. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q 's and W 's. Do not rearrange the balance or combine with other balances.
6. (20) Adiabatic steam turbines I and II are each 85% efficient. Determine the work produced in each turbine (kJ/kg). Provide the numbers used for any interpolation.



Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING

ChE 321: Chemical Engineering Thermodynamics

Spring 2002

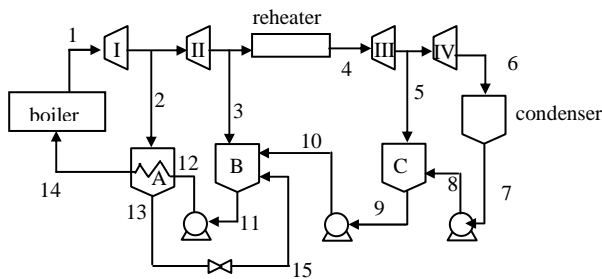
Exam 1 - Open Book, closed notes, 2/20/02, SUBMIT ALL ORIGINAL PAGES.

1. An ideal gas enters a valve at 400K and 3.4 MPa at 2 mol/min. It is throttled to 0.2 MPa. For the ideal gas, $C_p/R = 8.851$ is independent of T.

(a) (5) What is the outlet temperature?

(b) (10) What is the rate of entropy generation (kJ/min-K)?

The next few problems consider the combined reheat and regenerative cycle shown below. Unit A is a closed feedwater preheater. Units B and C are open feedwater preheaters. The turbines and pumps are adiabatic.



	P(MPa)	T(C)	H (kJ/kg)	S(kJ/kg-K)
1	6	500	3423.1	6.8826
2	2	350	3137.7	6.9583
3	0.6		3062.0	7.3740
4	2	450		
5	0.2			
6	0.03			
7	0.03			
8				
9				
10				
11	0.6	158.83	670.38	
12	6		678.4	
13	2		908.5	
14	6	200	857.5	
15	0.6			

2. (10) Fill in the missing pressures in the table.

3. (10) Determine the quality of stream 15.

Name _____

3. (20) Turbines III and IV are each 85% efficient. Determine the work produced in each turbine (kJ/kg). Provide the numbers used for interpolation.

4. (10) For stream 14, at the given T, P, use calculations to verify the tabulated value of H_{14} .

5. (10) Perform an energy balance around preheater A to determine \dot{m}_2 / \dot{m}_1 .

6. An ordinary vapor compression refrigeration cycle operates using ethane. The condenser operates at 1 MPa and the evaporator operates at 0.2 MPa.

MARK THE ATTACHED CHART AS YOU USE IT. SUBMIT THE CHART WITH YOUR WORK SO THAT APPROPRIATE PARTIAL CREDIT MY BE GIVEN FOR INCORRECT ANSWERS.

(a) (10) Determine the work per kg of ethane required in the compressor (85% efficient).

(c) (15) Determine the COP for the cycle.

DEPARTMENT OF CHEMICAL ENGINEERING

ChE 321: Thermodynamics
Exam 1, closed book

Spring 2001

1. One mole of an ideal gas ($C_p = 7/2R$) in a closed piston/cylinder is reversibly expanded from $T^i = 700K$, $P^i = 0.75 \text{ MPa}$ to $P^f = 0.1 \text{ MPa}$ by the following pathways. For each pathway, calculate W_S and ΔH .

a) (10) isothermal

b) (10) adiabatic

2. Answer the following questions using the schematic on the next page. This table is provided for your convenience. You need only to furnish the requested values.

(a) (10) Determine the pressures for streams 8-12 and enter them in the table.

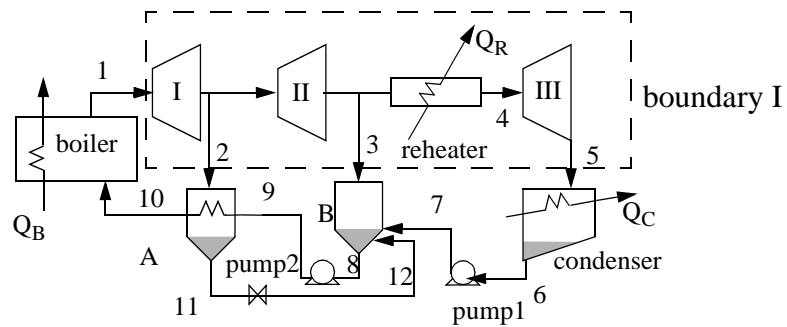
(b) (15) Determine the outlet enthalpy and W_S' (in kJ/kg) for adiabatic turbine I based on the assumption that the turbine is reversible.

(c) (10) Determine the outlet enthalpy, entropy and W_S (in kJ/kg) for adiabatic turbine I if turbine I is 80% efficient.

(d) (5) Write the energy balance for preheater A and find \dot{m}_2/\dot{m}_1 .

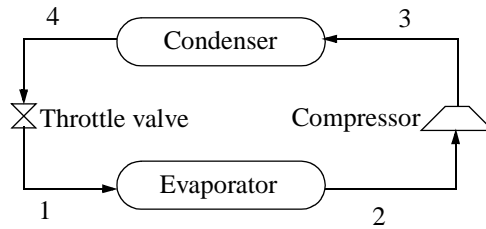
(e) (10) For boundary I, write the energy balance for steam. All turbines are adiabatic. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q 's and W_S 's. Do not rearrange the balance or combine with other balances.

- (f) (10) Write the energy balance around preheater B. Eliminate all mass flowrates except for \dot{m}_3/\dot{m}_1 and \dot{m}_2/\dot{m}_1 . Rearrange to solve for \dot{m}_3/\dot{m}_1 based on a known value of \dot{m}_2/\dot{m}_1 . Leave the enthalpies as variables; you do not need to punch the final formula into your calculator.



	P(MPa)	T(C)	H(kJ/kg)	S(kJ/kg-K)
1	8	600	3642.4	7.0221
2	1.2			
3	0.2	150		
4	0.2	300		
5	0.01			
6	0.01		191.8	
7	0.2		192.0	
8				
9			512.5	
10			763.8	
11			798.2	
12				

3. A refrigeration cycle using ammonia as a refrigerant operates on a ordinary vapor compression cycle shown below. Note the attached ammonia property diagram. Mark your answers clearly on the diagram. The diagram will be evaluated as part of your solution. The outlet of the condenser is to be 320 K. The outlet of the evaporator is to be 260 K.



- a. (5) Determine the pressures of the condenser and evaporator.
 evaporator P(MPa) _____
 condenser P(MPa) _____

- b. (5) Determine the power required in the adiabatic compressor (kW) if the refrigerant flow is to be 120 kg/hr. The compressor is to be 85% efficient.

- (c) (10) Determine the cooling capacity of the refrigerator per kg of NH_3 circulated.

pg 4 Ammonia Diagram

ChE 321: Chemical Engineering Thermodynamics
Exam 1, Feb 21, 2000
Open Book, Closed Notes

Spring, 2000

General Instructions

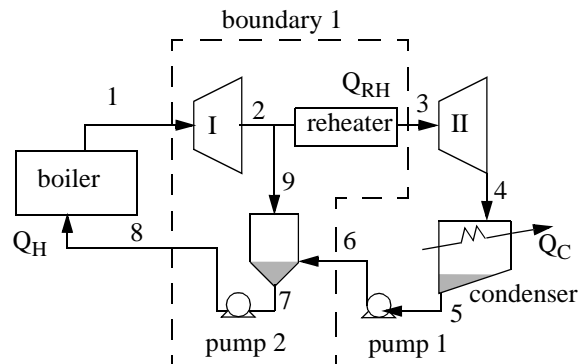
1. Submit all problems in the order of the exam.
2. Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
3. For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
4. Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1. Nitrogen is to be compressed from 25°C and 0.1 MPa to 2.5 MPa in a single-stage steady-state flow reversible adiabatic compressor. The heat capacity may be considered temperature independent, $C_p = 29.1\text{ J/mol-K}$

(a) (5) What is the outlet temperature of the compressor?

(b) (5) How much work must be furnished (kW) for compression of 50 kmol/hr ?

2. A power cycle using steam as the working fluid involves one reheater and one open feedwater preheater as shown below and tabulated in the table. The stage efficiency of Turbine I is 85% . The energy balances for the boiler, reheater, and condenser should consider just the process-fluid side of the heat exchangers.



NOTE: Not all values are required in the table. The table is provided for convenience.

Stream	T(°C)	P(MPa)	H(kJ/kg)	S(kJ/kg-K)
1	400	4.0	3214.5	6.7714
2		0.4		
3	400	0.4	3273.9	7.9002
4		0.01	2611.9	
5				
6				
7				
8				
9				

(a) (20) Determine the enthalpy of stream 2.

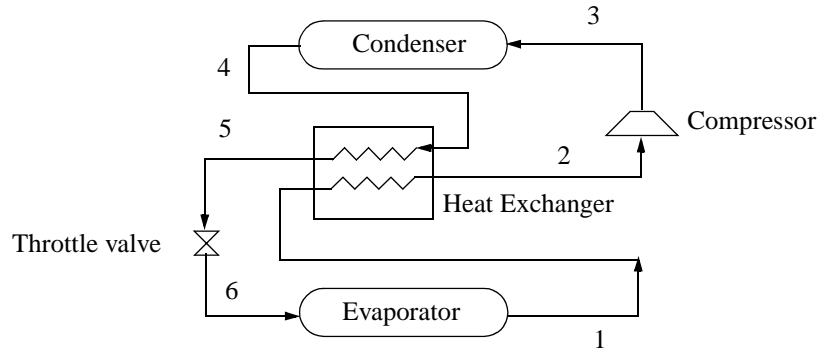
(b) (5) Determine the heat transfer necessary in the reheater (kJ/kg).

(c) (10) Provide the formula for work produced by the turbines per kg of feed from the boiler. You may leave the mass flowrates of streams 1 and 3 as unknown variables, but insert known enthalpy values.

(d) (10) Determine the enthalpy of stream 8 and the work performed by pump 2 (kJ/kg) if the pump is 80% efficient.

- (e) (10) Write the energy balance for boundary 1 as drawn in the schematic. Leave the energy balance in terms of variables, do not insert numerical values.

3. The refrigeration cycle below uses R-134a. Stream 1 is saturated vapor at 252K and stream 4 is saturated liquid at 1 MPa. Stream 2 is at 20°C.



NOTE: Not all values in table are required. Table provided for convenience.

Stream	T(°C)	P(MPa)	H(kJ/kg)	S(kJ/kg-K)
1 (sat V)	-21			
2	20			
3				
4 (sat L)		1		
5				
6				

- (a) (10) Determine the work required in the compressor (kJ/kg) if the compressor is 85% efficient. Mark your work on the PH chart if you use it.

- (b) (10) Determine the temperature and enthalpy of stream 5.

(c) (5) Determine the quality of stream 6.

(d) (10) Determine the cooling capacity of the cycle per kg of fluid circulated (kJ/kg).

3. (15) If the turbine II is 80% efficient, determine the outlet state 3 {H,T,S}. Base your answer on the provided turbine inlet properties. Provide the numbers used for interpolation.

4. (10) Determine the enthalpies for states 12, 14 if the pumps 3 and 4 are reversible and if they are 85% efficient.

5. (10) Determine the flowrate of m_2/m_1 for reversible pump 4 and reversible turbines 1,2.

6. (20) Determine the total amount of heat required in the boiler per kg of stream 1 based on reversible turbines and pumps.

7. (10) Write the steady-state energy balance for the boundary marked for problem 7.

8. (10) Provide a formula to calculate the thermal efficiency of the power cycle. Express your answer using ONLY enthalpies of streams and mass flowrates.