NAME: Solution

ChBE 2130 Thermodynamics I
Fall 2015
Exam 2

Remember

- Write down relevant relationships needed to solve each problem
- Provide details, intermediate steps, and units
- Note any assumptions
- Show your work
- Where indicated, place your final answer on the ____________________________
- **Submit your crib sheet with your exam.**

Problem	Possible Points	Score
1	20	
2	24	
3	24	
4	32	
Crib Sheet	Yes No (-5)	
Total	100	

1. Concept Questions **[20 pts: 5 points each,** no partial credit within sub-problem]

- An ideal gas is compressed isothermally. What happens to the **entropy** of the gas?
  a. Increases
  b. Decreases
  c. Remains the same
  d. Not enough information to determine

Follow isotherm on PH diagram as P increases.
Alternatively, for ideal gas $\Delta S = \int \frac{C_p}{T} dT - \ln \frac{P}{P_0}$
$\int \frac{C_p}{T} dT \rightarrow 0$
for $P > P_0$, this term i. negative

- The pressure of an ideal gas is increased while keeping the entropy constant. What happens to the **enthalpy** of the gas?
  a. Increases
  b. Decreases
  c. Remains the same
  d. Not enough information to determine

Follow isotherm on PH diagram
Alternatively
$\Delta S = \int \frac{C_p}{T} dT - \ln \frac{P}{P_0} = 0$
$\int \frac{C_p}{T} dT = \ln \frac{P}{P_0}$ both terms are positive

for ideal gas H is f(T) if ΔT is positive, ΔH is posti

- A power plant operates using a hot reservoir of 350°C and a cold reservoir of 30°C. The system (heat engine) efficiency is 55% of the Carnot efficiency for these reservoirs. What is the system efficiency?
  a. 55%
  b. 50.3%
  c. 28.3%
  d. 26.7%

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{303}{623} = 0.514$$

$$\eta_{actual} = 0.55\ \eta_{Carnot} = 0.55(0.514)$$

- Which of the following systems is isentropic?
  a. An adiabatic system
  b. An isothermal system
  c. A reversible adiabatic system
  d. A reversible isothermal system

rigid

2. A closed vessel containing 4 lb_m of saturated vapor methane has a total volume of 4 ft^3 (State 1). The surroundings are at 80°F. Heat transfers from the surroundings to the vessel until the final temperature of the methane is 80°F (State 2).
Note: Temperature conversion of °F + 460 = °R and Entropy values on the diagram are in units of btu lb_m/R where R is °Rankine

a. **[6 pts]** What is the final pressure (State 2)?

350 psia

$V = \frac{4\,ft^3}{4\,lb_m} = 1\,ft^3/lb_m$ constant volume process

b. **[8 pts]** What is the entropy change of methane?

$\Delta S = S_2 - S_1 = (1.28 - 1.00)\ btu/lb_m R$

From Methane Diagram

0.28 btu/lb_mR
or 1.12 btu/R

c. **[10 pts]** If the heat transfer is 420 btu, what is the total entropy generation?

0.34 btu/R
or 0.085 btu/lb_mR

$$\Delta S_{TOT} = \Delta S_{system} + \Delta S_{surroundings}$$

$$\Delta S_{system} = 4\,lb_m\left(0.28\,\frac{btu}{lb_m R}\right) = 1.12\ btu/R$$

$$\Delta S_{surrounding} = \frac{Q}{T} = \frac{-420\ btu}{(80+460)R}$$

Sign is negative because heat is leaving the surroundings

$$= -0.78\ btu/R$$

$$\Delta S_{TOT} = 1.12\,\frac{btu}{R} - 0.78\,\frac{btu}{R} = 0.34\ btu/R$$

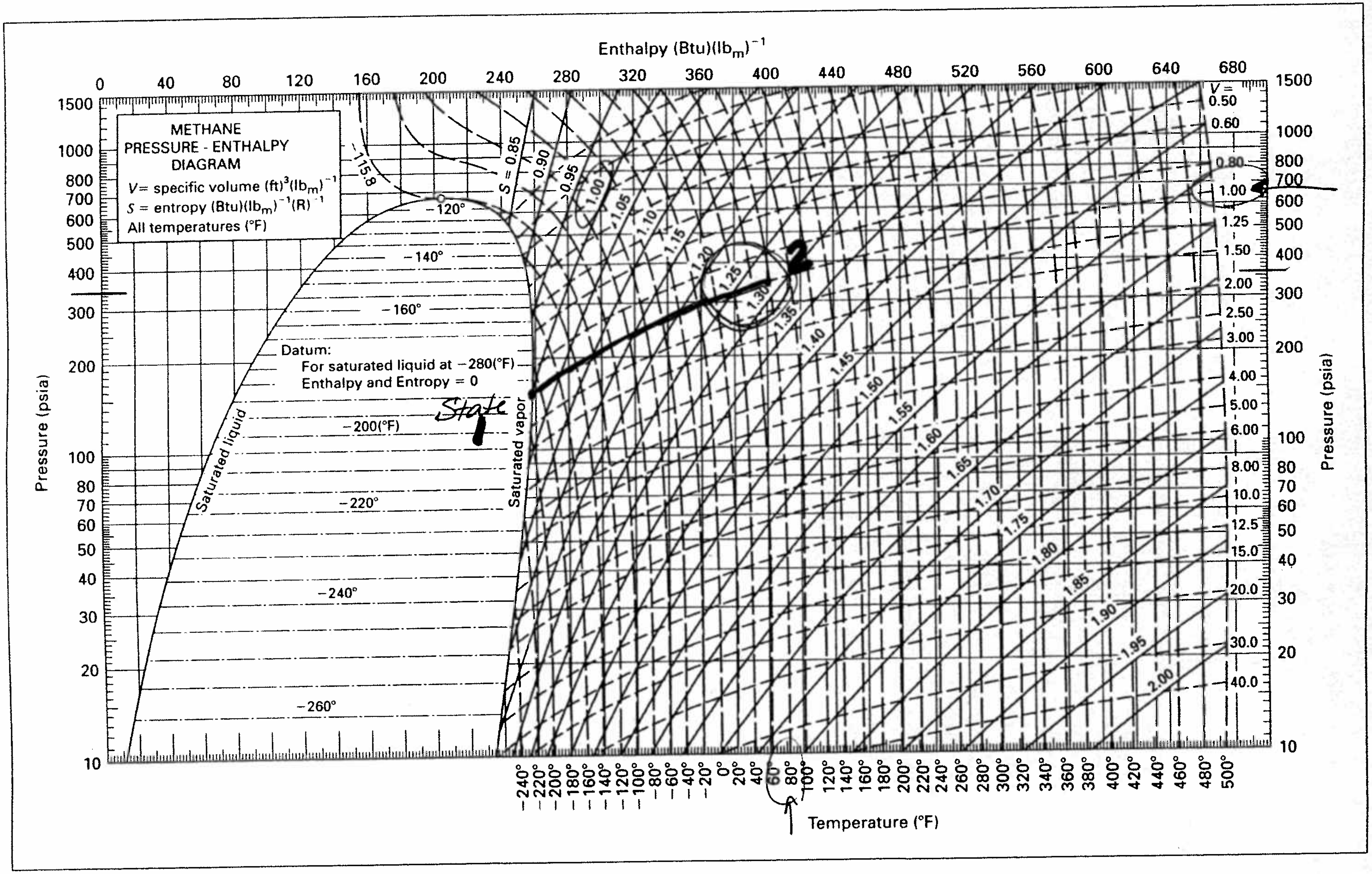


Figure G.1: *P H* diagram for methane. (*Reproduced by permission of the Shell Development Company, Copyright 1945*. Published by C. S. Matthews and C. O. Hurd, *Trans. AIChE*, vol. 42, pp. 55–78, 1946.)

3. An inventor proposes a process whereby 1.5 kmol of an ideal gas (constant C_p = 30 kJ/kmol K) is taken from 10 bar and 300 K to 1 bar and 500 K in a non-flow closed system. The process receives 50,000 kJ of heat reversibly from the surroundings at 300 K. The process produces work.
Note: For an ideal gas, $C_p - C_v = R$

a. **[12 pts]** Based upon an energy balance, how much work is produced?

Non-flow closed system $\quad\quad$ $-43,494$ kJ

$n\,\Delta U = Q + W \quad\quad T_1 = 300K$ to $T_2 = 500K$

$\Delta U = C_v\,dT$ for ideal gas $\quad\quad C_v = C_p - R = 30 - 8.314 = 21.686\ \text{J/mol K}$

$$1500\,\text{mol}\left(21.686\frac{\text{J}}{\text{mol K}}\right)(500-300)\,\text{K} = (50\,000 \times 1000)\,\text{J} + W$$

$$W = -4.35 \times 10^7\ \text{J} \text{ or } -43,494\ \text{kJ}$$

b. **[12 pts]** Is the process feasible (i.e. consistent with the 2nd Law)?

Entropy Balance $\quad\quad$ Not feasible

$$\Delta S_{univ} = \Delta S_{system} + \Delta S_{surroundings}$$

$$\Delta S_{system} = n\left[\int \frac{C_p}{T}\,dT - R\ln\frac{P_2}{P_1}\right] = n\left[C_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right]$$

$$\Delta S_{system} = 1500\,\text{mol}\left[30\ \text{J/mol K}\left(\ln\left(\frac{500}{300}\right)\right) - 8.314\frac{\text{J}}{\text{mol K}}\ln\left(\frac{1}{10}\right)\right]$$

$$\Delta S_{system} = 51.7\ \text{kJ/K}$$

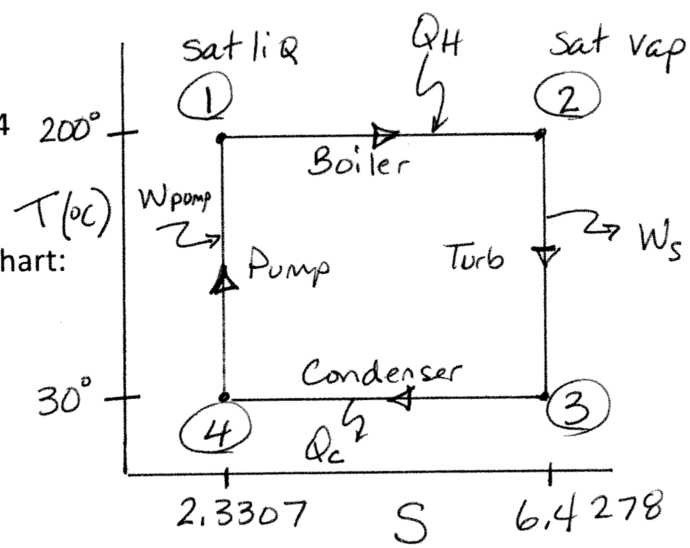
$$\Delta S_{surround} = \frac{Q}{T} = \frac{-50,000\ \text{kJ}}{300\ \text{K}} = -166.7\ \text{kJ/K}$$

$$\Delta S_{univ} = 51.7\ \text{kJ/K} - 166.7\ \text{kJ/K} = -115\ \text{kJ/K}$$

$\Delta S_{univ} \neq 0$ so impossible

4. Consider a Carnot Cycle operating on steam (Steam Table Attached). The fluid is condensed at 30°C and evaporated at 200°C. The process steps are:

Isothermal expansion from State 1 to 2
Adiabatic expansion from State 2 to 3
Isothermal compression from State 3 to 4
Adiabatic compression from State 4 to 1



a. **[12 pts]** Complete the following chart:

State	Temp (°C)	Entropy (kJ/ kg K)
1	200	2.3307
2	200	6.4278
3	30	6.4278
4	30	2.3307

At 200°C

$H_{sat vap} = 2790.9$ kJ/kg

$H_{sat liQ} = 852.4$ kJ/kg

Note that State 3 and 4 are mixed phase, not Saturated

b. **[8 pts]** Determine the heat transfer in the boiler in kJ/kg

Boiler → No Shaft work PV combines with U to get ΔH

$\underline{1938.5 \text{ kJ/kg}}$

$$\Delta H_{12} = Q_{12} + \underbrace{\cancel{W_{s12}}}_{0}$$

$$Q_{12} = \Delta H_{12} = (2790.9 - 852.4)\ \text{kJ/kg}$$

$$Q_{12} = 1938.5\ \text{kJ/kg}$$

Alternatively

$$Q_{12} = T(S_{12}) = (\underset{(+273.15)}{200}\ \overset{K}{})(6.4278 - 2.3307)\ \text{kJ/kgK}$$

c. **[8 pts]** Determine the cycle efficiency

0.359 or

35.9%

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{30+273}{200+273}$$

d. **[4 pts]** Suppose that the turbine and pump operated at 85% efficiency. In other words, they did **not** operate isentropically (there was irreversibility in the equipment operation). Compare the entropy change of the steam for one complete cycle with the ~~entropy change~~ of a reversible cycle. Does ΔS increase, decrease, or remain the same?

$\Delta S = 0$

Remains the Same

Entropy is a state function. If the steam completes one cycle it returns to the original state and $\Delta S = 0$. This is true whether the cycle is reversible or irreversible.

ΔS_{univ} (or total ΔS) will increase.

Table F.1. Saturated Steam, SI Units (Continued)

t °C	T K	P kPa	Specific Volume V sat. liq.	Specific Volume V evap.	Specific Volume V sat. vap.	Internal Energy U sat. liq.	Internal Energy U evap.	Internal Energy U sat. vap.	Enthalpy H sat. liq.	Enthalpy H evap.	Enthalpy H sat. vap.	Entropy S sat. liq.	Entropy S evap.	Entropy S sat. vap.
130	403.15	270.13	1.070	667.1	668.1	546.0	1993.4	2539.4	546.3	2173.6	2719.9	1.6344	5.3917	7.0261
132	405.15	286.70	1.072	630.8	631.9	554.5	1986.9	2541.4	554.8	2167.8	2722.6	1.6555	5.3507	7.0061
134	407.15	304.07	1.074	596.9	598.0	563.1	1980.4	2543.4	563.4	2161.9	2725.3	1.6765	5.3099	6.9864
136	409.15	322.29	1.076	565.1	566.2	571.6	1973.8	2545.4	572.0	2155.9	2727.9	1.6974	5.2695	6.9669
138	411.15	341.38	1.078	535.3	536.4	580.2	1967.2	2547.4	580.5	2150.0	2730.5	1.7182	5.2293	6.9475
140	413.15	361.38	1.080	507.4	508.5	588.7	1960.6	2549.3	589.1	2144.0	2733.1	1.7390	5.1894	6.9284
142	415.15	382.31	1.082	481.2	482.3	597.3	1953.9	2551.2	597.7	2137.9	2735.6	1.7597	5.1499	6.9095
144	417.15	404.20	1.084	456.6	457.7	605.9	1947.2	2553.1	606.3	2131.8	2738.1	1.7803	5.1105	6.8908
146	419.15	427.09	1.086	433.5	434.6	614.4	1940.5	2554.9	614.9	2125.7	2740.6	1.8008	5.0715	6.8723
148	421.15	451.01	1.089	411.8	412.9	623.0	1933.7	2556.8	623.5	2119.5	2743.0	1.8213	5.0327	6.8539
150	423.15	476.00	1.091	391.4	392.4	631.6	1926.9	2558.6	632.1	2113.2	2745.4	1.8416	4.9941	6.8358
152	425.15	502.08	1.093	372.1	373.2	640.2	1920.1	2560.3	640.8	2106.9	2747.7	1.8619	4.9558	6.8178
154	427.15	529.29	1.095	354.0	355.1	648.9	1913.2	2562.1	649.4	2100.6	2750.0	1.8822	4.9178	6.8000
156	429.15	557.67	1.098	336.9	338.0	657.5	1906.3	2563.8	658.1	2094.2	2752.3	1.9023	4.8800	6.7823
158	431.15	587.25	1.100	320.8	321.9	666.1	1899.3	2565.5	666.8	2087.7	2754.5	1.9224	4.8424	6.7648
160	433.15	618.06	1.102	305.7	306.8	674.8	1892.3	2567.1	675.5	2081.3	2756.7	1.9425	4.8050	6.7475
162	435.15	650.16	1.105	291.3	292.4	683.5	1885.3	2568.8	684.2	2074.7	2758.9	1.9624	4.7679	6.7303
164	437.15	683.56	1.107	277.8	278.9	692.1	1878.2	2570.4	692.9	2068.1	2761.0	1.9823	4.7309	6.7133
166	439.15	718.31	1.109	265.0	266.1	700.8	1871.1	2571.9	701.6	2061.4	2763.1	2.0022	4.6942	6.6964
168	441.15	754.45	1.112	252.9	254.0	709.5	1863.9	2573.4	710.4	2054.7	2765.1	2.0219	4.6577	6.6796
170	443.15	792.02	1.114	241.4	242.6	718.2	1856.7	2574.9	719.1	2047.9	2767.1	2.0416	4.6214	6.6630
172	445.15	831.06	1.117	230.6	231.7	727.0	1849.5	2576.4	727.9	2041.1	2769.0	2.0613	4.5853	6.6465
174	447.15	871.60	1.120	220.3	221.5	735.7	1842.2	2577.8	736.7	2034.2	2770.9	2.0809	4.5493	6.6302
176	449.15	913.68	1.122	210.6	211.7	744.4	1834.8	2579.3	745.5	2027.3	2772.7	2.1004	4.5136	6.6140
178	451.15	957.36	1.125	201.4	202.5	753.2	1827.4	2580.6	754.3	2020.2	2774.5	2.1199	4.4780	6.5979
180	453.15	1002.7	1.128	192.7	193.8	762.0	1820.0	2581.9	763.1	2013.1	2776.3	2.1393	4.4426	6.5819
182	455.15	1049.6	1.130	184.4	185.5	770.8	1812.5	2583.2	772.0	2006.0	2778.0	2.1587	4.4074	6.5660
184	457.15	1098.3	1.133	176.5	177.6	779.6	1804.9	2584.5	780.8	1998.8	2779.6	2.1780	4.3723	6.5503
186	459.15	1148.8	1.136	169.0	170.2	788.4	1797.3	2585.7	789.7	1991.5	2781.2	2.1972	4.3374	6.5346
188	461.15	1201.0	1.139	161.9	163.1	797.2	1789.7	2586.9	798.6	1984.2	2782.8	2.2164	4.3026	6.5191
190	463.15	1255.1	1.142	155.2	156.3	806.1	1782.0	2588.1	807.5	1976.7	2784.3	2.2356	4.2680	6.5036
192	465.15	1311.1	1.144	148.8	149.9	814.9	1774.2	2589.2	816.5	1969.3	2785.7	2.2547	4.2336	6.4883
194	467.15	1369.0	1.147	142.6	143.8	823.8	1766.4	2590.2	825.4	1961.7	2787.1	2.2738	4.1993	6.4730
196	469.15	1428.9	1.150	136.8	138.0	832.7	1758.6	2591.3	834.4	1954.1	2788.4	2.2928	4.1651	6.4578
198	471.15	1490.9	1.153	131.3	132.4	841.6	1750.6	2592.3	843.4	1946.4	2789.7	2.3117	4.1310	6.4428
200	473.15	1554.9	1.156	126.0	127.2	850.6	1742.6	2593.2	852.4	1938.6	2790.9	2.3307	4.0971	6.4278
202	475.15	1621.0	1.160	121.0	122.1	859.5	1734.6	2594.1	861.4	1930.7	2792.1	2.3495	4.0633	6.4128
204	477.15	1689.3	1.163	116.2	117.3	868.5	1726.5	2595.0	870.5	1922.8	2793.2	2.3684	4.0296	6.3980
206	479.15	1759.8	1.166	111.6	112.8	877.5	1718.3	2595.8	879.5	1914.7	2794.3	2.3872	3.9961	6.3832
208	481.15	1832.6	1.169	107.2	108.4	886.5	1710.1	2596.6	888.6	1906.6	2795.3	2.4059	3.9626	6.3686
210	483.15	1907.7	1.173	103.1	104.2	895.5	1701.8	2597.3	897.7	1898.5	2796.2	2.4247	3.9293	6.3539
212	485.15	1985.2	1.176	99.09	100.26	904.5	1693.5	2598.0	906.9	1890.2	2797.1	2.4434	3.8960	6.3394
214	487.15	2065.1	1.179	95.28	96.46	913.6	1685.1	2598.7	916.0	1881.8	2797.9	2.4620	3.8629	6.3249
216	489.15	2147.5	1.183	91.65	92.83	922.7	1676.6	2599.3	925.2	1873.4	2798.6	2.4806	3.8298	6.3104
218	491.15	2232.4	1.186	88.17	89.36	931.8	1668.0	2599.8	934.4	1864.9	2799.3	2.4992	3.7968	6.2960