國立雲林科技大學
八十九學年度研究所碩士班入學考試試題
系所：化工所
科目：化工熱力學

1. Steam at 2,100 kPa and 260℃ expands in a throttling process to 125 kPa. What is the temperature of the steam in its final state and what is its entropy change? If steam were an ideal gas, what would be its final temperature and its entropy change? You may refer to the steam table in the following for the calculation. (15 points)

Superheated Steam, SI units

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 75 (348.15)	100 (373.15)	125 (398.15)	150 (423.15)	175 (448.15)	200 (473.15)	225 (498.15)	250 (523.15)
	V	1.044	1673.0	....	1673.0	1792.7	1910.7	2027.7	2143.8	2259.3	2374.5
101.325	U	418.959	2506.5	....	2506.5	2544.7	2582.6	2620.4	2658.1	2695.9	2733.9
(100.00)	H	419.064	2676.0	....	2676.0	2728.4	2776.2	2825.8	2875.3	2924.8	2974.5
	S	1.3069	7.3554	....	7.3554	7.4860	7.6075	7.7213	7.8288	7.9308	8.0280
	V	1.049	1374.8	....	....	1449.1	1545.6	1641.0	1735.6	1829.6	1923.2
125	U	444.224	2513.4	....	....	2542.9	2581.2	2619.3	2657.2	2695.2	2733.3
(105.99)	H	444.356	2685.2	....	....	2724.0	2774.4	2824.4	2874.2	2923.9	2973.7
	S	1.3740	7.2847	....	....	7.3844	7.5072	7.6219	7.7300	7.8324	7.9300
	V	1.053	1159.0	....	....	1204.0	1285.2	1365.2	1444.4	1523.0	1601.3
150	U	466.968	2519.5	....	....	2540.9	2579.7	2618.1	2656.3	2694.4	2732.7
(111.37)	H	467.128	2693.4	....	....	2721.5	2772.5	2822.9	2872.9	2922.9	2872.9
	S	1.4336	7.2234	....	....	7.2953	7.4194	7.5352	7.6439	7.7468	7.8447
	V	1.057	1003.34	....	....	1028.8	1099.1	1168.2	1236.4	1304.1	1371.3
175	U	486.815	2524.7	....	....	2538.9	2578.2	2616.9	2655.3	2693.7	2732.1
(116.06)	H	467.000	2700.3	....	....	2718.0	2770.5	2821.3	2871.7	2921.9	2972.0
	S	1.4849	7.1716	....	....	7.2191	7.3447	7.4614	7.5708	7.6741	7.7724
	V	1.061	885.44	....	....	897.47	959.54	1020.4	1080.4	1139.8	1198.9
200	U	504.489	2529.2	....	....	2536.9	2576.6	2615.7	2654.4	2692.9	2731.4
(120.23)	H	504.701	2706.3	....	....	2716.4	2768.5	2819.8	2870.5	2920.9	2971.2
	S	1.5301	7.1268	....	....	7.1523	7.2794	7.3971	7.5072	7.6110	7.7096
	V	1.064	792.97	....	....	795.25	850.97	905.44	959.06	1012.1	1064.7
225	U	520.465	2533.2	....	....	2534.8	2576.1	2614.5	2653.5	2692.2	2730.6
(123.99)	H	520.705	2711.6	....	....	2713.6	2766.5	2818.2	2869.3	2919.9	2970.4
	S	1.5705	7.0873	....	....	7.0928	7.2213	7.3400	7.4508	7.5551	7.6540

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 200 (473.15)	225 (498.15)	250 (523.15)	275 (548.15)	300 (573.15)	325 (598.15)	350 (623.15)	375 (648.15)
	V	1.166	113.38	....	120.39	128.85	136.82	144.45	151.87	159.12	166.27
1750	U	876.234	2595.7	....	2637.6	2687.7	2734.5	2779.3	2822.7	2865.3	2907.4
(205.72)	H	878.274	2794.1	....	2848.2	2913.2	2974.0	3032.1	3088.4	3143.7	3198.4
	S	2.3846	6.3853	....	6.4961	6.5233	6.7368	6.8405	6.9368	7.0273	7.1133
	V	1.168	110.32	....	116.69	124.99	132.76	140.24	147.48	154.55	161.51
1800	U	882.472	2596.3	....	2635.5	2686.1	2733.3	2778.2	2821.6	2864.5	2906.7
(207.11)	H	884.574	2794.8	....	2845.5	2911.0	2972.3	3030.7	3087.3	3142.7	3197.5
	S	2.3976	6.3751	....	6.4787	6.6071	6.7214	6.8257	6.9223	7.0131	7.0993
	V	1.170	107.41	....	113.19	121.33	128.98	136.26	143.33	150.23	157.02
1850	U	888.585	2596.8	....	2633.3	2684.4	2732.0	2777.2	2820.9	2863.8	2906.1
(208.47)	H	890.750	2795.5	....	2842.6	2908.9	2970.6	3029.3	3086.1	3141.7	3196.6
	S	2.4103	6.3651	....	6.4616	6.5912	6.7064	6.8112	6.9082	6.9993	7.0856
	V	1.172	104.65	....	109.87	117.87	125.35	132.49	139.39	146.14	152.76
1900	U	894.580	2597.3	....	2631.2	2682.6	2730.7	2776.2	2820.1	2863.0	2905.4
(209.80)	H	896.807	2796.1	....	2840.0	2906.7	2968.6	3027.9	3084.9	3140.7	3195.7
	S	2.4226	6.3554	....	6.4448	6.5757	6.6917	6.7970	6.8944	6.9857	7.0723
	V	1.174	102.031	....	106.72	114.58	121.91	128.90	135.66	142.25	148.72
1950	U	900.461	2597.7	....	2629.0	2681.1	2729.4	2775.1	2819.2	2862.3	2904.8
(211.10)	H	902.752	2796.7	....	2837.1	2904.6	2967.1	3026.5	3083.7	3139.7	3194.8
	S	2.4349	6.3459	....	6.4283	6.5604	6.6772	6.7831	6.8809	6.9725	7.0583
	V	1.177	99.536	....	103.72	111.45	118.65	125.50	132.11	138.56	144.89
2000	U	906.236	2598.2	....	2626.9	2679.5	2728.1	2774.0	2818.3	2861.5	2904.1
(212.37)	H	908.589	2797.2	....	2834.3	2902.4	2965.4	3025.0	3082.5	3138.6	3193.9
	S	2.4469	6.3366	....	6.4120	6.5454	6.6631	6.7696	6.8677	6.9596	7.0468
	V	1.181	94.690	....	98.147	105.64	112.59	119.16	125.53	131.70	137.76
2100	U	917.479	2598.9	....	2622.4	2676.1	2725.4	2771.9	2816.5	2860.0	2902.8
(214.85)	H	919.959	2798.2	....	2828.5	2897.9	2961.9	3022.2	3080.1	3136.6	3192.1
	S	2.4700	6.3167	....	6.3802	6.5162	6.6356	6.7432	6.8422	6.9347	7.0220
	V	1.185	90.652	....	93.067	100.35	107.07	113.43	119.53	125.47	131.28
2200	U	928.346	2599.6	....	2617.9	2672.7	2722.7	2769.7	2814.7	2858.5	2901.5
(217.24)	H	930.953	2799.1	....	2822.7	2893.4	2958.3	3019.3	3077.7	3134.5	3190.3
	S	2.4922	6.3015	....	6.3492	6.4879	6.6091	6.7179	6.8177	6.9107	6.9985
	V	1.189	88.769	....	88.420	95.513	102.03	108.18	114.06	119.77	125.36
2300	U	938.668	2600.2	....	2613.3	2669.2	2720.0	2767.5	2812.9	2857.0	2900.2
(219.55)	H	941.601	2799.8	....	2818.7	2888.9	2954.7	3018.4	3075.3	3132.4	3188.6
	S	2.5136	6.2849	....	6.3190	6.4605	6.5835	6.6935	6.7941	6.8677	6.9759

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2. A high-velocity nozzle is designed to operate with steam at 700 kPa and 300°C. At the nozzle inlet the velocity is 30 ms^{-1}. Calculate values of the ratio A/A_1(where A_1 is the cross sectional area of the nozzle inlet) for the sections where the pressure is 600 kPa. Assume that the nozzle operates isentropically(i.e. reversible adiabatic process). (25 points)

Superheated steam, SI units

V = specific volume, cu cm/g, U = specific internal energy, kJ/kg
H = specific enthalpy, kJ/kg, S = specific entropy, kJ/(kg K)

ABS PRESS KPA (SAT TEMP) DEG C		SAT WATER	SAT STEAM	TEMPERATURE, DEG C (TEMPERATURE, K) 150 (423.15)	175 (448.15)	200 (473.15)	220 (493.15)	240 (513.15)	260 (533.15)	280 (553.15)	300 (573.15)
650 (155.47)	V	1.097	342.48	....	361.60	385.19	403.65	421.59	439.38	457.00	474.48
	U	655.199	2563.3	....	2598.0	2640.6	2673.8	2706.4	2738.6	2770.6	2802.6
	H	655.802	2751.7	....	2796.8	2852.5	2895.7	2938.3	2980.3	3022.0	3063.5
	S	1.8970	6.7870	....	6.8900	7.0108	7.1004	7.1849	7.2653	7.3421	7.4158
575 (157.18)	V	1.099	328.41	....	345.20	367.90	385.64	402.85	419.92	436.81	453.56
	U	662.603	2564.8	....	2596.6	2639.6	2672.9	2705.7	2738.0	2770.1	2802.1
	H	663.235	2753.6	....	2795.1	2851.1	2894.6	2937.3	2979.5	3021.3	3062.9
	S	1.9142	6.7720	....	6.8664	6.9880	7.0781	7.1630	7.2436	7.3206	7.3945
600 (158.84)	V	1.101	315.47	....	330.16	352.04	369.03	385.68	402.08	418.31	434.39
	U	669.762	2566.2	....	2595.3	2638.5	2672.1	2705.0	2737.4	2769.6	2801.6
	H	670.423	2755.6	....	2793.3	2849.7	2893.5	2936.4	2978.7	3020.6	3062.3
	S	1.9308	6.7575	....	6.8437	6.9662	7.0567	7.1419	7.2228	7.3000	7.3740
625 (160.44)	V	1.103	303.64	....	316.31	337.45	353.83	369.87	385.67	401.28	416.75
	U	676.695	2567.5	....	2593.9	2637.5	2671.2	2704.2	2736.8	2769.1	2801.2
	H	677.384	2757.2	....	2791.6	2848.4	2892.3	2935.4	2977.8	3019.9	3061.7
	S	1.9469	6.7437	....	6.8217	6.9451	7.0361	7.1217	7.2028	7.2802	7.3544
650 (161.99)	V	1.105	292.49	....	303.53	323.98	339.80	355.29	370.52	385.56	400.47
	U	683.417	2568.7	....	2592.5	2636.4	2670.3	2703.5	2736.2	2768.5	2800.7
	H	684.135	2758.9	....	2789.8	2847.0	2891.2	2934.4	2977.0	3019.2	3061.0
	S	1.9623	6.7304	....	6.8004	6.9247	7.0162	7.1021	7.1835	7.2611	7.3355
675 (163.49)	V	1.106	282.23	....	291.69	311.51	326.81	341.78	356.49	371.01	385.39
	U	689.943	2570.0	....	2591.1	2635.4	2669.5	2702.8	2735.6	2768.0	2800.3
	H	690.689	2760.5	....	2788.0	2845.6	2890.1	2933.5	2976.2	3018.5	3060.4
	S	1.9773	6.7176	....	6.7798	6.9050	6.9970	7.0833	7.1650	7.2428	7.3173
700 (164.96)	V	1.108	272.68	....	280.69	299.92	314.75	329.23	343.46	357.50	371.39
	U	696.285	2571.1	....	2589.7	2634.3	2668.6	2702.1	2735.0	2767.5	2799.8
	H	697.061	2762.0	....	2786.2	2844.2	2888.9	2932.5	2975.4	3017.7	3059.8
	S	1.9918	6.7052	....	6.7698	6.8859	6.9784	7.0651	7.1470	7.2250	7.2997
725 (166.38)	V	1.110	263.77	....	270.45	289.13	303.61	317.55	331.33	344.92	358.36
	U	702.457	2572.2	....	2588.3	2633.2	2667.7	2701.3	2734.3	2767.0	2799.3
	H	703.261	2763.4	....	2784.4	2842.8	2887.7	2931.5	2974.6	3017.0	3059.1
	S	2.0059	6.6932	....	6.7404	6.8673	6.9604	7.0474	7.1296	7.2078	7.2827

3. Calculate the heat capacity of a gas sample from the following information: The sample comes to equilibrium in a flask at 25℃ and 121.3 kPa. A stopcock is opened briefly, allowing the pressure to drop to 101.3 kPa. With the stopcock closed, the flask warms, returning to 25℃, and the pressure is measured as 104.0 kPa. Determine Cp in J mol^{-1} K^{-1} assuming the gas to be ideal and the expansion of the gas remaining in the flask to be reversible and adiabatic. (20 points)

4. Define the following terms:
   (a) Partial properties (5 points)
   (b) Excess properties (5 points) $M^E = M - M^{id}$
   (c) Residual properties (5 points)

5. (a) Show that the differential of the entropy for an ideal gas can be written

$$dS_{ideal} = (C_p/T)dT - (nR/P)dP \qquad \text{(15 points)}$$

   (b) What is the change in molar entropy of helium in the following process?

$$1\ \text{He}(298\ \text{K},\ 1\ \text{bar}) \longrightarrow 1\ \text{He}(100\ \text{K},\ 10\ \text{bar})$$

   Assume that He is an ideal monatomic gas. (10 points)

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1. 已知恆溫下，某反應物 A 分解反應包含兩個進行路徑，即

$$A \rightarrow R \quad (\text{需求產物}) \qquad \text{反應速率常數 } k_1$$

$$A \rightarrow S \quad (\text{非需求產物}) \qquad \text{反應速率常數 } k_2$$

且其對應的反應速率方程式分別為：

$$r_R = k_1 C_A$$

$$r_S = k_2 C_A^{0.5}$$

請問若反應進行以單一反應器完成，你將選擇何種類型之反應器，方可使反應之需求產物在較小反應器容積下，可獲得需求產物較高之產率？(10%)

2.已知物質 A 於具回流率（recycle ratio）R 之 PFR 反應器（plug flow reactor）進行一自催化反應（autocatalytic reaction）之基本反應（elementary reaction），其產物為 S，此反應速率常數為 0.1 liter/（mole . min），若進料只有 A，且其進料濃度與流率分別為 1 mole/liter 及 1 mole/min，當產物轉化率為 0.98 時，

（a）請計算此條件下所需之最小的容積（15%）

（b）若反應條件改為 進料有 95 % A 與 5% S，反應亦進行同一自催化反應（autocatalytic reaction）之基本反應 （elementary reaction），且其進料濃度與流率分別為 1 mole/liter 及 1 mole/min，請計算無回流裝置下，一 CFSTR（constant flow stirred tank reactor）反應器後接一 PFR 反應器，且第一個反應器轉化率為 0.5，總反應產物為 5 % A 與 95% S 所須的空間時間（space-time）為何？（10%）

3.已知有一反應進行的方式如下：

$$A \rightarrow S, \quad r_S = (0.001\ \text{min}^{-1})\, C_A$$

若進料只有 A，其濃度為 1 mole/liter 之飽和溶液，進料成本取決於進料莫耳流率，且單位成本為 0.5/mole，今反應於一 CFSTR 反應器進行，且於此反應器後接一純化分離裝置，若純化分離裝置可將產物完全分離，所分離的反應物再完全送回進行反應，此純化分離裝置成本取決於分離裝置送回反應器再進行反應之莫耳流率，且單位成本為 0.25/mole ，而此 CFSTR 反應器成本取決於 CFSTR 反應器大小，且其成本為 0.03/（liter . hour），今若產物 S 之產率為 10 g . mole / hour，請計算此反應條件下最低的產物單位成本。（15%）

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4. (a) For isomerization of n-pentene (N) to i-pentene (I) over alumina

$$N_{(g)} \underset{}{\overset{Al_2O_3}{\rightleftharpoons}} I_{(g)}$$

the reaction mechanism is believed to be

Adsorption: $N_{(g)} + S \rightleftharpoons N \bullet S$

Surface reaction: $N \bullet S + S \rightleftharpoons I \bullet S + S$ (dual site)

Desorption: $I \bullet S \rightleftharpoons I_{(g)} + S$

where S represents an active (vacant) site on the surface of the catalyst, $N \bullet S$ or $I \bullet S$ represents that one unit of N or I is adsorbed on the site S.

Assuming each reaction step is an elementary reaction and the surface reaction is rate-limiting, <u>derive a rate law</u> for the isomerization rate of n-pentene. (15%)

(b) What is the temperature effect on the equilibrium constant of adsorption step? What is the approximate rate-law for the above reaction operated at high temperatures? (5%)

5. (a) <u>Show that</u> the rate law for the enzyme-catalyzed reaction sequence

$$E + S \underset{k_2}{\overset{k_1}{\rightleftharpoons}} E \bullet S \xrightarrow{k_3} E + P$$

is $-r_S = \dfrac{V_{max} C_S}{K_m + C_S}$ ---- (Michaeli – Menten equation)

where E, S, $E \bullet S$, and P represent the enzyme, substrate, the enzyme-substrate complex, and the reaction products, respectively, $-r_S$ is the rate of disappearance of the substrate, C_S is the concentration of the substrate, V_{max} and K_m are the Michaelis-Menten parameters. (15%)

(b) If the reaction is carried out in a batch reactor, <u>show that</u> the time to achieve a conversion X is

$$t = \frac{K_m}{V_{max}} \ln \frac{1}{1-X} + \frac{C_{S0} X}{V_{max}}$$

where C_{S0} is the initial concentration of the substrate. (10%)

(c) Design a batch reactor experiment for the enzyme-catalyzed reaction and explain how the parameters V_{max} and K_m can be determined from the batch reactor data. (5%)

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1. Define the following and give a descriptive analysis of the * numbers in terms of ratios of the system forces or transport properties. (20%)
   (a) Reynolds No.* (b) Prandtl No.
   (c) Pelect No.* (heat transfer) (d) Biot No.* (heat transfer)

2. Derive an expression for the "head loss" h_L equivalent to turbulent flow through a long smooth horizontal pipe of diameter D and length L, in terms of the friction factor. Ignore entrance and exit effects. (10%)

3. Crude oil flows at the rate of 2000 lb/hr through the inside pipe of a double pipe heat exchanger and is heated from 90 °F to 200 °F. The heat is supplied by kerosene initially at 450 °F flowing through the annular space. The overall coefficient, U, was found to be 80 Btu/hr-ft^2-°F. The specific heat of the oil and kerosene are 0.56 and 0.60 Btu/lb-°F, respectively. For safety reasons, the minimum temperature difference between the two fluids must be 20 °F.
   (a) Would the flow rate of the kerosene be greater for countercurrent or concurrent flow? Prove your answer! Show calculations. (5%)
   (b) Would the heat transfer area required be greater for countercurrent or concurrent flow? Prove your answer! Show calculations. (10%)

4. A storage tank for lubricating oil has a leak, and all of the oil from the leak flows down one flat side of one of the support legs. The support leg is 10 cm wide and makes a 75° angle with the ground. The flowing oil film (estimated to be 2 mm thick) covers the entire width of the support leg. The oil has a viscosity of 10 poise and a density of 0.82 g/cm^3. Estimate the rate of loss of oil per day in liters. (15%)

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5. Consider a one-dimensional diffusion of species A through a stationary cylinder medium (length = L, inner radius = r_1, outer radius = r_2) in which the molar (or mass) average velocity of the mixture is zero. The mole fraction of A at $r = r_1$ is x_{A1} and the mole fraction at $r = r_2$ is x_{A2} ($x_{A1} > x_{A2}$). For steady state conditions with no reactions, find the concentration profile of A in the cylinder medium. (15%)

6. An absorption column, 5 m tall, is being used to test a new type of structured packing. An air stream containing 1 mol% of ammonia is introduced to the column at a rate of 6 kmol/hr. The liquid stream is pure water entering at the top of the column at a rate of 10 kmol/hr. The concentration of ammonia in air at the top of the column is 0.05 mol%. The evaporation of water is negligible. The system follows Henry's Law for concentrations under 5 mol%, with a Henry's constant of 1.68 ($y^* = 1.68x^*$, x^* and y^* are the equilibrium mole fractions of ammonia in the liquid and gas phases, respectively).
(a) Determine the concentration of ammonia in the exiting water. (5%)
(b) Calculate the number of mass transfer units and the overall mass transfer coefficient based on the gas phase. (15%)
(c) Indicate the possible mass transfer mechanisms in a packed column from the microscopic viewpoint. (5%)