EG3029 Chemical Thermodynamics

Tutorial 4

Problem 1:

Steam entering a turbine at 4 MPa and 400°C expands reversibly and adiabatically.

(a) For what discharge pressure is the exit stream a saturated vapour? *(572.83 kPa)*

(b) Determine the steam quality for a discharge pressure of 250 kPa. *(0.949)*

(c) Draw both processes in a *TS* diagram.

Problem 2:

Calculate *V* and *Z* for sulphur hexafluoride at 75 °C and 15 bar by the following equations:

(a) The truncated virial equation $Z = \frac{PV}{RT} = 1 + \frac{B}{V} + \frac{C}{V^2}$ with B = -194 $cm^3\ mol^{-1}$ and C = 15,300 $cm^6\ mol^{-2}$. *(1722 $cm^3\ mol^{-1}$, 0.893)*

(b) The Redlich/Kwong equation. *(1714.1 $cm^3\ mol^{-1}$, 0.888)*

(c) The Soave/Redlich/Kwong equation. *(1726.9 $cm^3\ mol^{-1}$, 0.895)*

(d) The Peng/Robinson equation. *(1701.5 $cm^3\ mol^{-1}$, 0.882)*

For sulphur hexafluoride: T_c = 318.7 K, P_c = 37.6 bar, V_c = 198 $cm^3\ mol^{-1}$, ω = 0.286.

V = SPECIFIC VOLUME $cm^3\ g^{-1}$
U = SPECIFIC INTERNAL ENERGY $kJ\ kg^{-1}$
H = SPECIFIC ENTHALPY $kJ\ kg^{-1}$
S = SPECIFIC ENTROPY $kJ\ kg^{-1}\ K^{-1}$

Table F.2. Superheated Steam, SI Units (Continued)

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 225 (498.15)	250 (523.15)	275 (548.15)	300 (573.15)	325 (598.15)	350 (623.15)	375 (648.15)	400 (673.15)
	V	1.193	83.199	84.149	91.075	97.411	103.36	109.05	114.55	119.93	125.22
2400	U	949.066	2600.7	2608.6	2665.6	2717.3	2765.4	2811.1	2855.4	2898.8	2941.7
(221.78)	H	951.929	2800.4	2810.6	2884.2	2951.1	3013.4	3072.8	3130.4	3186.7	3242.3
	S	2.5343	6.2690	6.2894	6.4338	6.5586	6.6699	6.7714	6.8656	6.9542	7.0384
	V	1.197	79.905	80.210	86.985	93.154	98.925	104.43	109.75	114.94	120.04
2500	U	958.969	2601.2	2603.8	2662.0	2714.5	2763.1	2809.3	2853.9	2897.5	2940.6
(223.94)	H	961.962	2800.9	2804.3	2879.5	2947.4	3010.4	3070.4	3128.2	3184.8	3240.7
	S	2.5543	6.2536	6.2604	6.4077	6.5345	6.6470	6.7494	6.8442	6.9333	7.0178
	V	1.201	76.856	.....	83.205	89.220	94.830	100.17	105.32	110.33	115.26
2600	U	968.597	2601.5	.....	2658.4	2711.7	2760.9	2807.4	2852.3	2896.1	2939.4
(226.04)	H	971.720	2801.4	.....	2874.7	2943.6	3007.4	3067.9	3126.1	3183.0	3239.0
	S	2.5736	6.2387	.....	6.3823	6.5110	6.6249	6.7281	6.8236	6.9131	6.9979
	V	1.205	74.025	.....	79.698	85.575	91.036	96.218	101.21	106.07	110.83
2700	U	977.968	2601.8	.....	2654.7	2708.8	2758.6	2805.6	2850.7	2894.8	2938.2
(228.07)	H	981.222	2801.7	.....	2869.9	2939.8	3004.4	3065.4	3124.0	3181.2	3237.4
	S	2.5924	6.2244	.....	6.3575	6.4882	6.6034	6.7075	6.8036	6.8935	6.9787
	V	1.209	71.389	.....	76.437	82.187	87.510	92.550	97.395	102.10	106.71
2800	U	987.100	2602.1	.....	2650.9	2705.9	2756.3	2803.7	2849.2	2893.4	2937.0
(230.05)	H	990.485	2802.0	.....	2864.9	2936.0	3001.3	3062.8	3121.9	3179.3	3235.8
	S	2.6106	6.2104	.....	6.3331	6.4659	6.5824	6.6875	6.7842	6.8746	6.9601
	V	1.213	68.928	.....	73.395	79.029	84.226	89.133	93.843	98.414	102.88
2900	U	996.008	2602.3	.....	2647.1	2702.9	2754.0	2801.8	2847.6	2892.0	2935.8
(231.97)	H	999.524	2802.2	.....	2859.9	2932.1	2998.2	3060.3	3119.7	3177.4	3234.1
	S	2.6283	6.1969	.....	6.3092	6.4441	6.5621	6.6681	6.7654	6.8563	6.9421
	V	1.216	66.626	.....	70.551	76.078	81.159	85.943	90.526	94.969	99.310
3000	U	1004.7	2602.4	.....	2643.2	2700.0	2751.6	2799.9	2846.0	2890.7	2934.6
(233.84)	H	1008.4	2802.3	.....	2854.8	2928.2	2995.1	3057.7	3117.5	3175.6	3232.5
	S	2.6455	6.1837	.....	6.2857	6.4228	6.5422	6.6491	6.7471	6.8385	6.9246
	V	1.220	64.467	.....	67.885	73.315	78.287	82.958	87.423	91.745	95.965
3100	U	1013.2	2602.5	.....	2639.2	2697.0	2749.2	2797.9	2844.3	2889.3	2933.4
(235.67)	H	1017.0	2802.3	.....	2849.6	2924.2	2991.9	3055.1	3115.4	3173.7	3230.8
	S	2.6623	6.1709	.....	6.2626	6.4019	6.5227	6.6307	6.7294	6.8212	6.9077
	V	1.224	62.439	.....	65.380	70.721	75.593	80.158	84.513	88.723	92.829
3200	U	1021.5	2602.5	.....	2635.2	2693.9	2746.8	2796.0	2842.7	2887.9	2932.1
(237.45)	H	1025.4	2802.3	.....	2844.4	2920.2	2988.7	3052.5	3113.2	3171.8	3229.2
	S	2.6786	6.1585	.....	6.2398	6.3815	6.5037	6.6127	6.7120	6.8043	6.8912
	V	1.227	60.529	.....	63.021	68.282	73.061	77.526	81.778	85.883	89.883
3300	U	1029.7	2602.5	.....	2631.1	2690.8	2744.4	2794.0	2841.1	2886.5	2930.9
(239.18)	H	1033.7	2802.3	.....	2839.0	2916.1	2985.5	3049.9	3110.9	3169.9	3227.5
	S	2.6945	6.1463	.....	6.2173	6.3614	6.4851	6.5951	6.6952	6.7879	6.8752
	V	1.231	58.728	.....	60.796	65.982	70.675	75.048	79.204	83.210	87.110
3400	U	1037.6	2602.5	.....	2626.9	2687.7	2741.9	2792.0	2839.4	2885.1	2929.7
(240.88)	H	1041.8	2802.1	.....	2833.6	2912.0	2982.2	3047.2	3108.7	3168.0	3225.9
	S	2.7101	6.1344	.....	6.1951	6.3416	6.4669	6.5779	6.6787	6.7719	6.8595
	V	1.235	57.025	.....	58.693	63.812	68.424	72.710	76.776	80.689	84.494
3500	U	1045.4	2602.4	.....	2622.7	2684.5	2739.5	2790.0	2837.8	2883.7	2928.4
(242.54)	H	1049.8	2802.0	.....	2828.1	2907.8	2979.0	3044.5	3106.5	3166.1	3224.2
	S	2.7253	6.1228	.....	6.1732	6.3221	6.4491	6.5611	6.6626	6.7563	6.8443
	V	1.238	55.415	.....	56.702	61.759	66.297	70.501	74.482	78.308	82.024
3600	U	1053.1	2602.2	.....	2618.4	2681.3	2737.0	2788.0	2836.1	2882.3	2927.2
(244.16)	H	1057.6	2801.7	.....	2822.5	2903.6	2975.6	3041.8	3104.2	3164.2	3222.5
	S	2.7401	6.1115	.....	6.1514	6.3030	6.4315	6.5446	6.6468	6.7411	6.8294
	V	1.242	53.888	.....	54.812	59.814	64.282	68.410	72.311	76.055	79.687
3700	U	1060.6	2602.1	.....	2614.0	2678.0	2734.4	2786.0	2834.4	2880.8	2926.0
(245.75)	H	1065.2	2801.4	.....	2816.8	2899.3	2972.3	3039.1	3102.0	3162.2	3220.8
	S	2.7547	6.1004	.....	6.1299	6.2841	6.4143	6.5284	6.6314	6.7262	6.8149
	V	1.245	52.438	.....	53.017	57.968	62.372	66.429	70.254	73.920	77.473
3800	U	1068.0	2601.9	.....	2609.5	2674.7	2731.9	2783.9	2832.7	2879.4	2924.7
(247.31)	H	1072.7	2801.1	.....	2811.0	2895.0	2968.9	3036.4	3099.7	3160.3	3219.1
	S	2.7689	6.0896	.....	6.1085	6.2654	6.3973	6.5126	6.6163	6.7117	6.8007
	V	1.249	51.061	.....	51.308	56.215	60.558	64.547	68.302	71.894	75.372
3900	U	1075.3	2601.6	.....	2605.0	2671.4	2729.3	2781.9	2831.0	2877.9	2923.5
(248.84)	H	1080.1	2800.8	.....	2805.1	2890.6	2965.5	3033.6	3097.4	3158.3	3217.4
	S	2.7828	6.0789	.....	6.0872	6.2470	6.3806	6.4970	6.6015	6.6974	6.7868
	V	1.252	49.749	.....	.....	54.546	58.833	62.759	66.446	69.969	73.376
4000	U	1082.4	2601.3	.....	.....	2668.0	2726.7	2779.8	2829.3	2876.5	2922.2
(250.33)	H	1087.4	2800.3	.....	.....	2886.1	2962.0	3030.8	3095.1	3156.4	3215.7
	S	2.7965	6.0685	.....	.....	6.2288	6.3642	6.4817	6.5870	6.6834	6.7733

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

			SPECIFIC VOLUME *V*			INTERNAL ENERGY *U*			ENTHALPY *H*			ENTROPY *S*		
t °C	*T* K	*P* kPa	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.
75	348.15	38.55	1.026	4133.1	4134.1	313.9	2162.1	2476.0	313.9	2321.5	2635.4	1.0154	6.6681	7.6835
76	349.15	40.19	1.027	3974.6	3975.7	318.1	2159.2	2477.3	318.1	2318.9	2637.1	1.0275	6.6418	7.6693
77	350.15	41.89	1.027	3823.3	3824.3	322.3	2156.3	2478.5	322.3	2316.4	2638.7	1.0395	6.6156	7.6551
78	351.15	43.65	1.028	3678.6	3679.6	326.5	2153.3	2479.8	326.5	2313.9	2640.4	1.0514	6.5896	7.6410
79	352.15	45.47	1.029	3540.3	3541.3	330.7	2150.4	2481.1	330.7	2311.4	2642.1	1.0634	6.5637	7.6271
80	353.15	47.36	1.029	3408.1	3409.1	334.9	2147.4	2482.3	334.9	2308.8	2643.8	1.0753	6.5380	7.6132
81	354.15	49.31	1.030	3281.6	3282.6	339.1	2144.5	2483.5	339.1	2306.3	2645.4	1.0871	6.5123	7.5995
82	355.15	51.33	1.031	3160.6	3161.6	343.3	2141.5	2484.8	343.3	2303.8	2647.1	1.0990	6.4868	7.5858
83	356.15	53.42	1.031	3044.8	3045.8	347.5	2138.6	2486.0	347.5	2301.2	2648.7	1.1108	6.4615	7.5722
84	357.15	55.57	1.032	2933.9	2935.0	351.7	2135.6	2487.3	351.7	2298.6	2650.4	1.1225	6.4362	7.5587
85	358.15	57.80	1.033	2827.8	2828.8	355.9	2132.6	2488.5	355.9	2296.1	2652.0	1.1343	6.4111	7.5454
86	359.15	60.11	1.033	2726.1	2727.2	360.1	2129.7	2489.7	360.1	2293.5	2653.6	1.1460	6.3861	7.5321
87	360.15	62.49	1.034	2628.8	2629.8	364.3	2126.7	2490.9	364.3	2290.9	2655.3	1.1577	6.3612	7.5189
88	361.15	64.95	1.035	2535.4	2536.5	368.5	2123.7	2492.2	368.5	2288.4	2656.9	1.1693	6.3365	7.5058
89	362.15	67.49	1.035	2446.0	2447.0	372.7	2120.7	2493.4	372.7	2285.8	2658.5	1.1809	6.3119	7.4928
90	363.15	70.11	1.036	2360.3	2361.3	376.9	2117.7	2494.6	376.9	2283.2	2660.1	1.1925	6.2873	7.4799
91	364.15	72.81	1.037	2278.0	2279.1	381.1	2114.7	2495.8	381.1	2280.6	2661.7	1.2041	6.2629	7.4670
92	365.15	75.61	1.038	2199.2	2200.2	385.3	2111.7	2497.0	385.4	2278.0	2663.4	1.2156	6.2387	7.4543
93	366.15	78.49	1.038	2123.5	2124.5	389.5	2108.7	2498.2	389.6	2275.4	2665.0	1.2271	6.2145	7.4416
94	367.15	81.46	1.039	2050.9	2051.9	393.7	2105.7	2499.4	393.8	2272.8	2666.6	1.2386	6.1905	7.4291
95	368.15	84.53	1.040	1981.2	1982.2	397.9	2102.7	2500.6	398.0	2270.2	2668.1	1.2501	6.1665	7.4166
96	369.15	87.69	1.041	1914.3	1915.3	402.1	2099.7	2501.8	402.2	2267.5	2669.7	1.2615	6.1427	7.4042
97	370.15	90.94	1.041	1850.0	1851.0	406.3	2096.6	2503.0	406.4	2264.9	2671.3	1.2729	6.1190	7.3919
98	371.15	94.30	1.042	1788.3	1789.3	410.5	2093.6	2504.1	410.6	2262.2	2672.9	1.2842	6.0954	7.3796
99	372.15	97.76	1.043	1729.0	1730.0	414.7	2090.6	2505.3	414.8	2259.6	2674.4	1.2956	6.0719	7.3675
100	373.15	101.33	1.044	1672.0	1673.0	419.0	2087.5	2506.5	419.1	2256.9	2676.0	1.3069	6.0485	7.3554
102	375.15	108.78	1.045	1564.5	1565.5	427.4	2081.4	2508.8	427.5	2251.6	2679.1	1.3294	6.0021	7.3315
104	377.15	116.68	1.047	1465.1	1466.2	435.8	2075.3	2511.1	435.9	2246.3	2682.2	1.3518	5.9560	7.3078
106	379.15	125.04	1.049	1373.1	1374.2	444.3	2069.2	2513.4	444.4	2240.9	2685.3	1.3742	5.9104	7.2845
108	381.15	133.90	1.050	1287.9	1288.9	452.7	2063.0	2515.7	452.9	2235.4	2688.3	1.3964	5.8651	7.2615
110	383.15	143.27	1.052	1208.9	1209.9	461.2	2056.8	2518.0	461.3	2230.0	2691.3	1.4185	5.8203	7.2388
112	385.15	153.16	1.054	1135.6	1136.6	469.6	2050.6	2520.2	469.8	2224.5	2694.3	1.4405	5.7758	7.2164
114	387.15	163.62	1.055	1067.5	1068.5	478.1	2044.3	2522.4	478.3	2219.0	2697.2	1.4624	5.7318	7.1942
116	389.15	174.65	1.057	1004.2	1005.2	486.6	2038.1	2524.6	486.7	2213.4	2700.2	1.4842	5.6881	7.1723
118	391.15	186.28	1.059	945.3	946.3	495.0	2031.8	2526.8	495.2	2207.9	2703.1	1.5060	5.6447	7.1507
120	393.15	198.54	1.061	890.5	891.5	503.5	2025.4	2529.0	503.7	2202.2	2706.0	1.5276	5.6017	7.1293
122	395.15	211.45	1.062	839.4	840.5	512.0	2019.1	2531.1	512.2	2196.6	2708.8	1.5491	5.5590	7.1082
124	397.15	225.04	1.064	791.8	792.8	520.5	2012.7	2533.2	520.7	2190.9	2711.6	1.5706	5.5167	7.0873
126	399.15	239.33	1.066	747.3	748.4	529.0	2006.3	2535.3	529.2	2185.2	2714.4	1.5919	5.4747	7.0666
128	401.15	254.35	1.068	705.8	706.9	537.5	1999.9	2537.4	537.8	2179.4	2717.2	1.6132	5.4330	7.0462
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