UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2014/2015 Academic Session

June 2015

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains <u>SEVEN</u> printed pages and <u>TWO</u> printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi <u>TUJUH</u> muka surat yang bercetak dan <u>DUA</u> muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

<u>Instruction:</u> Answer **<u>ALL</u>** questions.

*[**<u>Arahan</u>**: Jawab **<u>SEMUA</u>** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai].

Answer ALL questions.

1. [a] Ethanol, water and acetone are mixed in a closed, well insulated system. If all these liquid was initially at 25°C, at what temperature this mixture reaches equilibrium? If the pressure inside this closed system is 101.325 kPa, determine the state of the system?

[5 marks]

[b] A personal computer is to be examined from a thermodynamic perspective. Determine the direction of the work and heat transfers (in or out) when the following are taken as the system: (i) keyboard, (ii) monitor, (iii) processing unit, and, (iv) all of these taken as system.

[10 marks]

[c] A well insulated rigid tank which contains 0.9 kg of air at 35°C and 325 kPa was subjected to a constant stirring for 25 minutes with the paddle wheel operated at power rating of 0.030 kW. Determine the final temperature of the air. Assume air is an ideal gas with average molar mass of 28.97 g/mol.

[10 marks]

2. [a] A Carnot engine is used to maintain the temperature of a refrigerator at –10°C by removing heat from it at a rate of 300 kJ/min. If the surrounding air is at 25°C, determine the minimum power input required for this refrigerator. What is the electricity cost to operate this engine for 10 days? Sketch a diagram to illustrate the terms used in the calculations.

Given: $\eta = 1 - (T_L/T_H)$ and electricity tariff in Malaysia is 21.8 cent/kWh.

[5 marks]

[b] The well insulated vessel shown in figure Q.2.[b] is initially evacuated. The supply line contains air is maintained at 1,500 kPa and 35°C. The valve is opened until the pressure in the container is the same as the pressure in the supply line.

[i] Perform mass and energy balance of the system.

[ii] Use the balances done in part [b].[i] to determine the minimum temperature in the container when the valve is closed.

[10 marks]

Given: $\Delta s = c_p ln\frac{T_2}{T_1} - Rln\frac{P_2}{P_1}$.

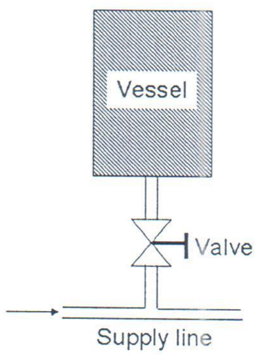


Figure Q.2.[b]

Jawab SEMUA soalan.

1. [a] *Etanol, air dan aseton dicampurkan dalam satu sistem yang tertutup dan bertebat haba. Apakah suhu campuran ini pada keadaan keseimbangan, sekiranya semua cecair itu memiliki suhu awal 25°C? Tekanan dalaman tertutup sistem ialah 101.325 kPa, tentukan keadaan sistem?*

[5 markah]

[b] *Analisa daripada perspektif termodinamik telah dijalankan pada sebuah komputer peribadi. Sila tentukan arah aliran haba dan kerja (sama ada memasuki atau keluar daripada sistem) apabila berikut dianggap sebagai sistem:(i) papan kekunci, (ii) monitor, (iii) unit pemprosesan, dan, (iv) semua bahagian.*

[10 markah]

[c] *Sebuah tangki tegar dengan ciri penebatan haba mengandungi 0.9 kg udara pada 35°C dan 325 kPa tertakluk pada pengacauan berterusan selama 25 minit dengan roda dayung yang beroperasi pada kuasa 0.030 kW. Tentukan suhu akhir udara. Andaikan udara adalah gas unggul dengan jisim molar 28.97 g/mol.*

[10 markah]

2. [a] *Sebuah enjin Carnot telah digunakan untuk mengekalkan suhu peti sejuk pada -10°C dengan mengeluarkan haba daripadanya pada kadar 300 kJ/min. Jika udara sekeliling adalah pada 25°C, tentukan kuasa minimum yang diperlukan untuk peti sejuk ini. Berapakah kos elektrik bagi mesin yang beroperasi selama 10 hari? Lakarkan sebuah rajah menunjukkan istilah yang digunakan dalam pengiraan.*

Diberi: $\eta = 1 - (T_L/T_H)$ *dan tarif elektrik di Malaysia ialah 21.8 sen/kWj.*

[5 markah]

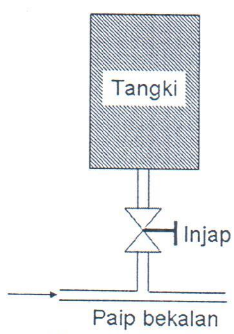
[b] *Tangki tebat haba yang ditunjukkan dalam Rajah S.2.[b] telah dikosongkan sepenuhnya. Paip bekalan yang mengandungi udara dikekalkan pada 1,500 kPa dan 35°C. Injap telah dibuka sehingga tekanan dalam tangki tersebut sama seperti tekanan dalam paip bekalan.*

[i] *Lakukan imbangan jisim dan tenaga bagi sistem ini.*

[ii] *Gunakan imbangan yang dijalankan di [b].[i] untuk menentukan suhu minimum dalam tangki berkenan selepas injap ditutup semula.*

[10 markah]

Diberi: $\Delta s = c_p ln\frac{T_2}{T_1} - Rln\frac{P_2}{P_1}$.



Rajah S.2.[b].

[c] According to Big Bang Theory, universe started as a very 'hot-spot' with billion degree celsius of temperature follow with continuous expansion of its volume. Does continuous expansion of universe violate the 1st Law of Thermodynamics? By using the understanding of 1st and 2nd Laws, predict the final state of the universe (in term of temperature). Entropy $\Delta s = \Delta Q/T$.

[10 marks]

3. The Claude liquefaction process is to be applied to methane. Using the schematic of Figure Q.3. for stream numbering, the key variables depend on the fraction of stream 3 that is liquefied, $\dot{m}_8/\dot{m}_3$, and the fraction of stream 3 that is fed through the expander, $\dot{m}_5/\dot{m}_3$.

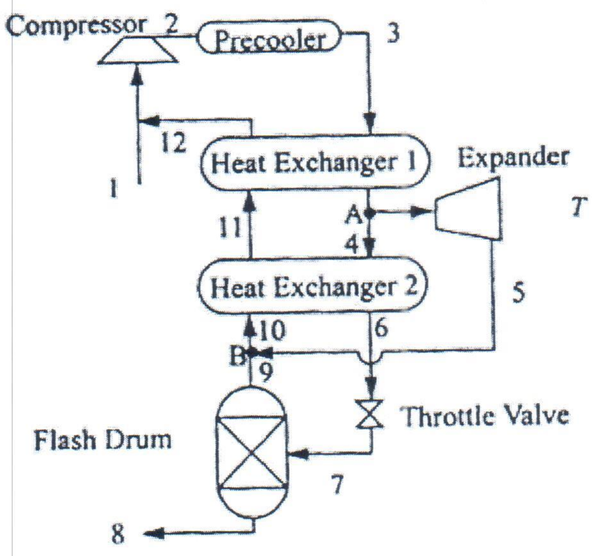


Figure Q.3

[a] Write a mass balance for the system boundary encompassing all equipment except the compressor and precooler.

[2 marks]

[b] Write an energy balance for the same boundary described in part [a], and show

$$\frac{\dot{m}_8}{\dot{m}_3} = \frac{(H_3 - H_{12}) + (\frac{\dot{m}_5}{\dot{m}_3}) W_{S\ expander}}{(H_3 - H_{12})}$$

[4 marks]

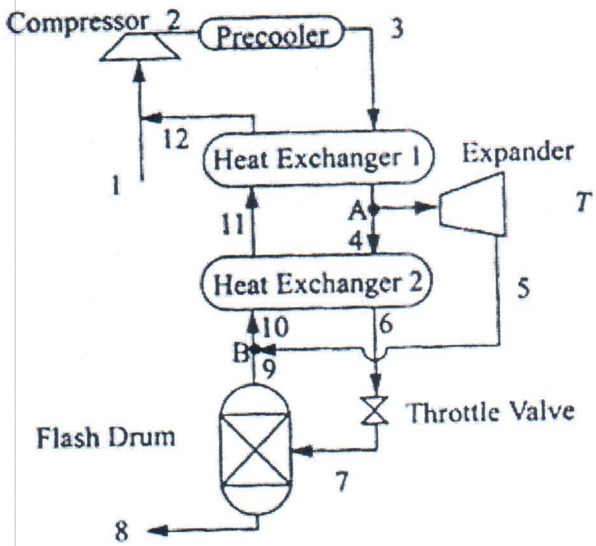
[c] Stream 3 is at 300 K and 3 MPa, stream 4 is at 280 K and 3 MPa, stream 12 is at 290 K and 0.1 MPa, and the flash drum is operated at 0.1 MPa. The expander has an efficiency of 91%. The fraction liquefied is $\dot{m}_8/\dot{m}_3 = 0.15$. Determine how much flow to direct through the expander, $\dot{m}_5/\dot{m}_3$.

[9 marks]

[c] *Menurut Teori Big Bang, alam semesta kita bermula sebagai satu 'titik panas' dengan suhu bilion darjah selsius diikuti dengan pengembangan isipadu berterusan. Adakah pengembangan berterusan alam semesta melanggar Hukum Termodinamik Pertama? Dengan menggunakan pemahaman anda dalam Hukum Termodinamik Pertama dan Kedua, ramalkan keadaan akhir alam semesta (berdasarkan terma suhu akhir). Entropi* $\Delta s = \Delta Q/T$.

[10 markah]

3. *Proses pencecairan Claude akan dilakukan terhadap metana. Gunakan skematik dalam Rajah S.3 untuk penomboran aliran; pembolehubah utama bergantung kepada pecahan aliran 3 yang mencair,* $\dot{m}_8/\dot{m}_3$, *dan pecahan aliran 3 yang disuap melalui pengembang* $\dot{m}_5/\dot{m}_3$.



Rajah S.3

[a] *Tuliskan keseimbangan jisim untuk sempadan sistem merangkumi semua peralatan kecuali pemampat dan pra-penyejuk.*

[2 markah]

[b] *Tuliskan keseimbangan tenaga untuk sempadan yang sama di atas [a], dan tunjukkan*

$$\frac{\dot{m}_8}{\dot{m}_3} = \frac{(H_3 - H_{12}) + (\frac{\dot{m}_5}{\dot{m}_3})W_{S\,pengembang}}{(H_3 - H_{12})}$$

[4 markah]

[c] *Aliran 3 pada 300 K dan 3 MPa, aliran 4 pada 280 K dan 3 MPa, aliran 12 pada 290 K dan 0.1 MPa, dan gelendung kilat beroperasi pada 0.1 MPa. Pengembang berkecekapan pada 91%. Pecahan pencairan* $\dot{m}_8/\dot{m}_3 = 0.15$. *Hitungkan jumlah aliran yang melalui pengembang,* $\dot{m}_5/\dot{m}_3$.

[9 markah]

[d] Find the enthalpies of streams 3- 12, and the temperatures and pressures. List all streams from low to high stream numbers in a Table.

[10 marks]

4. [a] Figure Q.4.[a] presented data for 2-propanol (1) + water (2). Calculate the excess Gibbs energy at $x_1 = 0.6369$ and fit the one-parameter Margules equation. Data from original citation provide *T*= 30°C, $P_1^{sat} = 60.7\ mmHg$, $P_2^{sat} = 32.1\ mmHg$, and $y_1 = 0.6462$ when $x_1 = 0.6369$ at $P = 66.9\ mmHg$.

[10 marks]

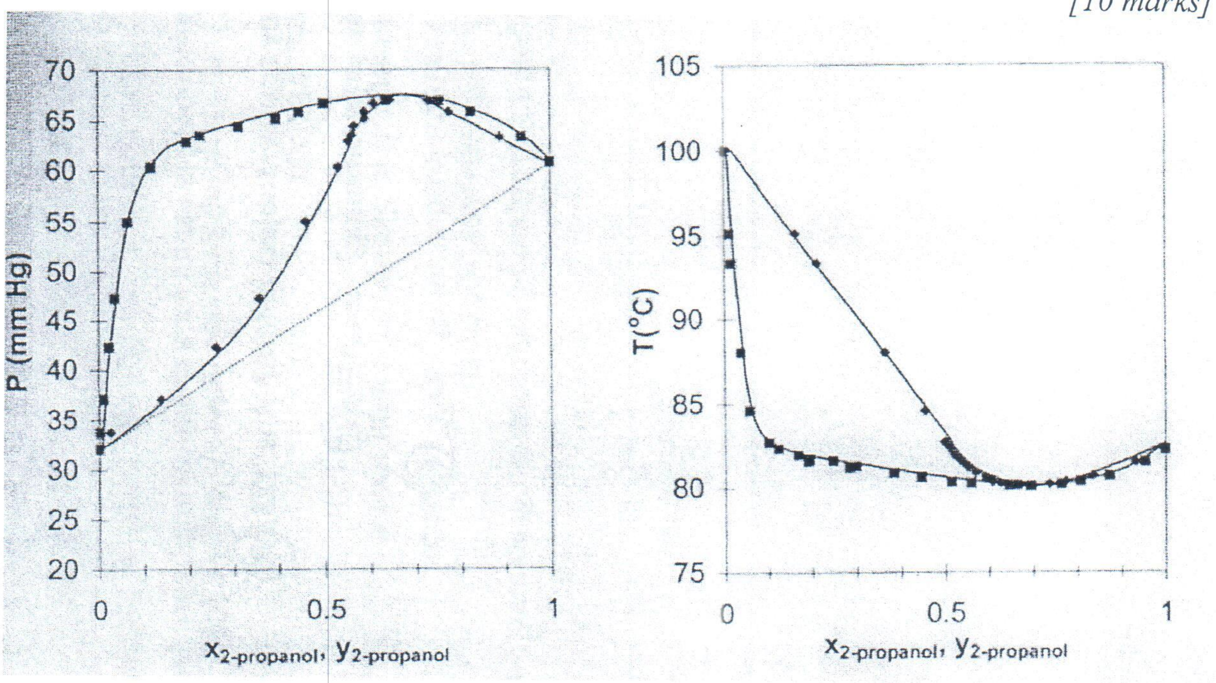


Figure Q.4.[a]. Phase behaviour of the 2-propanol + water system. Left figure at 30°C. Right figure at 760mmHg.

[b] Benzene and ethanol (e) form azeotropic mixture. Prepare a *y-x* and a *P-x-y* diagram for the benzene-ethanol system at 45°C assuming the mixture is ideal. Compare the results with the experimental data tabulated in Table Q.4.[b]. Briefly explain the azeothropic phenomena observed.

[15 marks]

Table Q.4.[b]. *P-x-y* experimental data for benzene-ethanol system

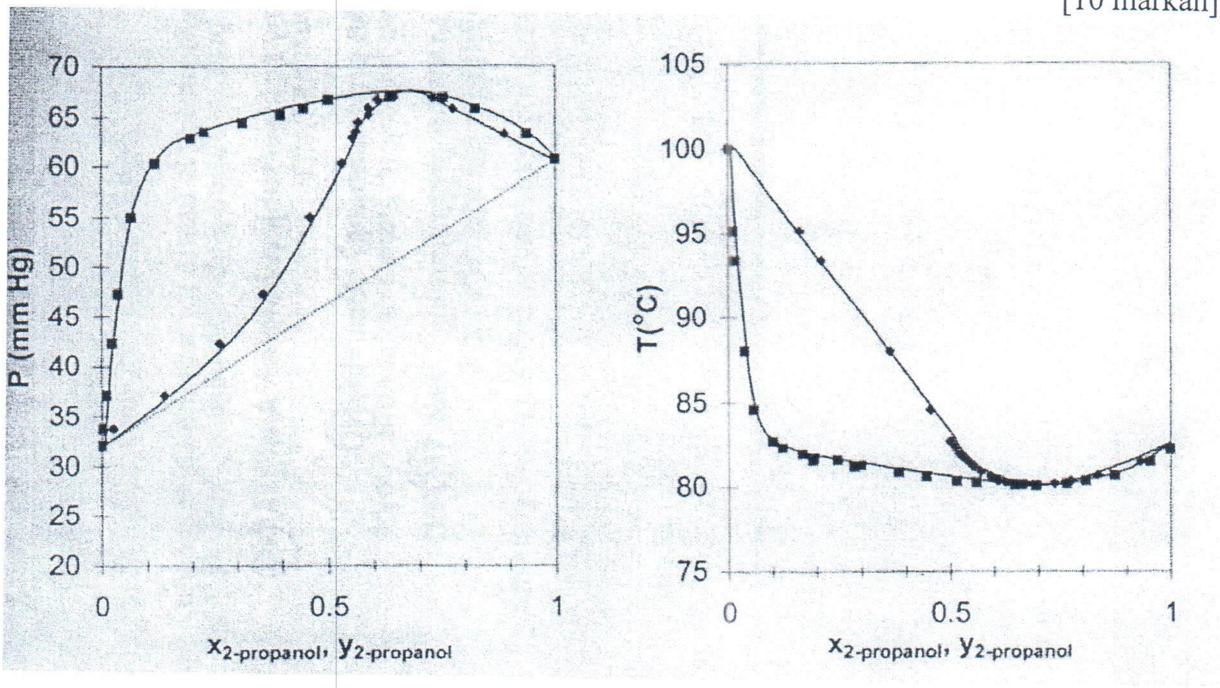
P, bar	x_e	y_e	P, bar	x_e	y_e
0.2939	0	0	0.4100	0.5199	0.4065
0.3613	0.0374	0.1965	0.4093	0.5284	0.4101
0.3953	0.0972	0.2895	0.4028	0.6155	0.4343
0.4088	0.2183	0.3370	0.3891	0.7087	0.4751
0.4124	0.3141	0.3625	0.2711	0.9591	0.8201
0.4120	0.4150	0.3842	0.2321	1.0000	1.0000

[d] *Carikan entalpi-entalpi untuk aliran 3-12, beserta suhu dan tekanan. Senaraikan dalam satu jadual semua aliran mengikut turutan dari rendah hingga tinggi.*

[10 markah]

4. [a] *Rajah S.4.[a] membentangkan data untuk 2-propanol (1) + air (2). Hitungkan tenaga Gibbs berlebihan pada* $x_1 = 0.6369$ *dan padankan persamaan Margules satu-parameter. Data dari petikan asal pada T=30°C,* $P_1^{sat} = 60.7\ mmHg$, $P_2^{sat} = 32.1\ mmHg$, *dan* $y_1 = 0.6462$ *apabila* $x_1 = 0.6369$ *pada* $P = 66.9\ mmHg$.

[10 markah]



Rajah S.4.[a]. Keadaan fasa sistem 2-propanol+air. Rajah kiri pada 30°C. Rajah kanan pada 760 mmHg.

[b] *Benzena dan etanol (e) menghasilkan campuran azetropik. Sediakan satu rajah* y-x *dan* P-x-y *untuk sistem benzena-etanol pada 45°C. Andaikan campuran adalah unggul. Bandingkan jawapan dengan data dari ekperimen di Jadual S.4.[b]. Terangkan secara ringkas fenomena azeotropik yang diperhatikan.*

[15 markah]

Jadual S.4.[b] Data eksperimen P-x-y *untuk sistem benzena etanol.*

P, bar	x_e	y_e	*P, bar*	x_e	y_e
0.2939	0	0	0.4100	0.5199	0.4065
0.3613	0.0374	0.1965	0.4093	0.5284	0.4101
0.3953	0.0972	0.2895	0.4028	0.6155	0.4343
0.4088	0.2183	0.3370	0.3891	0.7087	0.4751
0.4124	0.3141	0.3625	0.2711	0.9591	0.8201
0.4120	0.4150	0.3842	0.2321	1.0000	1.0000

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Appendix

Table C.1: Heat Capacities of Gases in the Ideal-Gas State†

Constants in equation $C_P^{ig}/R = A + BT + CT^2 + DT^{-2}$ T (kelvins) from 298 to T_{max}

Chemical species		T_{max}	$C_{P_{298}}^{ig}/R$	A	$10^3\ B$	$10^6\ C$	$10^{-5}\ D$
Paraffins:							
Methane	CH_4	1500	4.217	1.702	9.081	−2.164	
Ethane	C_2H_6	1500	6.369	1.131	19.225	−5.561	
Propane	C_3H_8	1500	9.011	1.213	28.785	−8.824	
n-Butane	C_4H_{10}	1500	11.928	1.935	36.915	−11.402	
iso-Butane	C_4H_{10}	1500	11.901	1.677	37.853	−11.945	
n-Pentane	C_5H_{12}	1500	14.731	2.464	45.351	−14.111	
n-Hexane	C_6H_{14}	1500	17.550	3.025	53.722	−16.791	
n-Heptane	C_7H_{16}	1500	20.361	3.570	62.127	−19.486	
n-Octane	C_8H_{18}	1500	23.174	4.108	70.567	−22.208	
1-Alkenes:							
Ethylene	C_2H_4	1500	5.325	1.424	14.394	−4.392	
Propylene	C_3H_6	1500	7.792	1.637	22.706	−6.915	
1-Butene	C_4H_8	1500	10.520	1.967	31.630	−9.873	
1-Pentene	C_5H_{10}	1500	13.437	2.691	39.753	−12.447	
1-Hexene	C_6H_{12}	1500	16.240	3.220	48.189	−15.157	
1-Heptene	C_7H_{14}	1500	19.053	3.768	56.588	−17.847	
1-Octene	C_8H_{16}	1500	21.868	4.324	64.960	−20.521	
Miscellaneous organics:							
Acetaldehyde	C_2H_4O	1000	6.506	1.693	17.978	−6.158	
Acetylene	C_2H_2	1500	5.253	6.132	1.952	......	−1.299
Benzene	C_6H_6	1500	10.259	−0.206	39.064	−13.301	
1,3-Butadiene	C_4H_6	1500	10.720	2.734	26.786	−8.882	
Cyclohexane	C_6H_{12}	1500	13.121	−3.876	63.249	−20.928	
Ethanol	C_2H_6O	1500	8.948	3.518	20.001	−6.002	
Ethylbenzene	C_8H_{10}	1500	15.993	1.124	55.380	−18.476	
Ethylene oxide	C_2H_4O	1000	5.784	−0.385	23.463	−9.296	
Formaldehyde	CH_2O	1500	4.191	2.264	7.022	−1.877	
Methanol	CH_4O	1500	5.547	2.211	12.216	−3.450	
Styrene	C_8H_8	1500	15.534	2.050	50.192	−16.662	
Toluene	C_7H_8	1500	12.922	0.290	47.052	−15.716	
Miscellaneous inorganics:							
Air		2000	3.509	3.355	0.575	......	−0.016
Ammonia	NH_3	1800	4.269	3.578	3.020	......	−0.186
Bromine	Br_2	3000	4.337	4.493	0.056	......	−0.154
Carbon monoxide	CO	2500	3.507	3.376	0.557	......	−0.031
Carbon dioxide	CO_2	2000	4.467	5.457	1.045	......	−1.157
Carbon disulfide	CS_2	1800	5.532	6.311	0.805	......	−0.906
Chlorine	Cl_2	3000	4.082	4.442	0.089	......	−0.344
Hydrogen	H_2	3000	3.468	3.249	0.422	......	0.083
Hydrogen sulfide	H_2S	2300	4.114	3.931	1.490	......	−0.232
Hydrogen chloride	HCl	2000	3.512	3.156	0.623	......	0.151
Hydrogen cyanide	HCN	2500	4.326	4.736	1.359	......	−0.725
Nitrogen	N_2	2000	3.502	3.280	0.593	......	0.040
Nitrous oxide	N_2O	2000	4.646	5.328	1.214	......	−0.928
Nitric oxide	NO	2000	3.590	3.387	0.629	......	0.014
Nitrogen dioxide	NO_2	2000	4.447	4.982	1.195	......	−0.792
Dinitrogen tetroxide	N_2O_4	2000	9.198	11.660	2.257	......	−2.787
Oxygen	O_2	2000	3.535	3.639	0.506	......	−0.227
Sulfur dioxide	SO_2	2000	4.796	5.699	0.801	......	−1.015
Sulfur trioxide	SO_3	2000	6.094	8.060	1.056	......	−2.028
Water	H_2O	2000	4.038	3.470	1.450	......	0.121

†Selected from H. M. Spencer, *Ind. Eng. Chem.*, vol. 40, pp. 2152–2154, 1948; K. K. Kelley, *U.S. Bur. Mines Bull. 584*, 1960; L. B. Pankratz, *U.S. Bur. Mines Bull. 672*, 1982.

E.10 PRESSURE-ENTHALPY DIAGRAM FOR METHANE

(Source: NIST, Thermophysics Division, Boulder, CO, USA, used with permission.)