UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2012/2013 Academic Session

June 2013

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains EIGHT printed pages and ONE printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN muka surat yang bercetak dan SATU muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

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

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

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Answer each of the following questions carefully:
Jawab setiap soalan-soalan berikut dengan teliti:

[i] Consider 2 beakers of water, in one beaker, the temperature of water is above room temperature, and the other is below room temperature. They are left on a table (they are not in contact with each other), after some time, equilibrium is reached. Explain how this is possible?

Pertimbangkan 2 bikar air, dalam satu bikar, suhu air melebihi suhu bilik, dan air dalam satu bikar lagi adalah di bawah suhu bilik. Kedua-dua bikar ini ditinggalkan di atas meja (kedua-dua bikar tidak bersentuhan antara satu sama lain), selepas masa tertentu, keseimbangan dicapai. Terangkan bagaimana ini boleh berlaku?

[2 marks/markah]

[ii] Consider a system that undergoes a perfectly reversible process, the change of entropy of the system can still be calculated as $dS_{system} = dQ_{rev}/T$. How a system which undergoes a reversible process could still experienced entropy gain/losses?

Pertimbangkan untuk satu sistem yang menjalani satu proses boleh balik secara sempurna, perubahan entropi sistem masih boleh diambil kira sebagai $dS_{system} = dQ_{rev}/T$. *Bagaimana sistem yang menjalani proses boleh balik masih boleh mengalami entropi pertambahan/penurunan?* *[2 marks/markah]*

[iii] Why are most of the compressed liquid or solid regions not included in the printed tables?

Mengapa kebanyakan data untuk cecair atau pepejal termampat tidak dimasukkan ke dalam jadual termodinamik? *[2 marks/markah]*

[iv] JK decided to make a cup of coffee by including sugar and milk. After adding hot water into the mixture and vigorously stirring it for 5 minutes, JK discovered there is still some undissolved sugar at the bottom of his cup. JK is thinking for a better solution to this problem and the first thing came into his mind is to perform a degree of freedom analysis. By using Gibbs Phase rule ($F = 2 - \pi + N$) help JK to determine whether he has extra degree of freedom (yes/no) to pursue other option(s) to promote the full dissolution of sugar.

JK memutuskan untuk membancuh secawan kopi dengan gula dan susu. Selepas menambah air panas ke dalam campuran ini dan mengacau selama 5 minit, JK mendapati masih terdapat gula yang tidak larut di bahagian bawah cawan. JK berpendapat bahawa untuk merangka penyelesaian yang lebih baik kepada masalah ini, perkara pertama yang datang ke fikiran beliau adalah untuk melakukan analisis darjah kebebasan. Dengan menggunakan aturan fasa Gibbs ($F = 2 - \pi + N$) sila tentukan sama ada JK mempunyai darjah kebebasan (ya/tidak) dalam menyelesaikan masalah ini.

[4 marks/markah]

[b] In a very hot, humid night JK stayed at home all alone and was overwhelmed with high temperature of his house. He decided to do a thermodynamic analysis of his place and find out how to mitigate this condition while his air-condition is working hard ($T_{house} < T_{environment}$).

Pada suatu malam yang sangat panas dan lembap, JK tinggal di rumah bersendirian dan merasa amat tidak selesa dengan suhu tinggi di rumahnya. Beliau memutuskan untuk melakukan analisis termodinamik ke atas tempat tinggal beliau dan untuk memahami bagaimana menangani keadaan ini sementara penghawa dingin rumah sedang bekerja ($T_{rumah} < T_{sekitar}$).

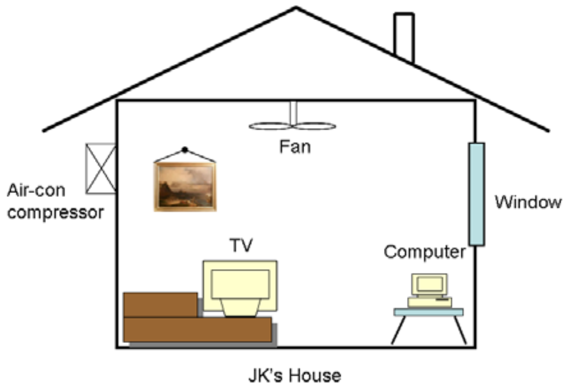

Figure Q.1.

Gambarajah S.1.

Since JK is not very good in thermodynamics, so he needs your help for the following tasks:

JK tidak mempunyai pemahaman yang tinggi dalam termodinamik, oleh itu JK memerlukan bantuan anda untuk melakukan tugas-tugas berikut:

[i] By taking JK's house in Taman Pekaka as a modeled problem as shown in Figure Q.1., define system, boundary and surrounding by sketch out your answer. (Aesthetic drawing would not contribute extra marks).

Dengan mengambil rumah JK di Taman Pekaka sebagai masalah seperti dimodelkan di dalam Gambarajah S.1., tentukan sistem, sempadan dan sekitarnya. Lakarkan jawapan anda secara ringkas.

[2 marks/markah]

[ii] Listed down, if any, what is the heat source(s) and work component(s) associated to your system as defined in [i].

Sekiranya ada, senaraikan sumber haba dan komponen kerja yang berkaitan dengan sistem anda, seperti ditentukan dalam [i].

[7 marks/markah]

[iii] Based on your answer in [ii], write down a mathematic expression to relate all the heat and work components to the internal energy of the house according to 1st Law of Thermodynamics ($\Delta U = \Delta Q + \Delta W$). Remember the direction of energy flow is important.

Berdasarkan jawapan anda di [ii], tuliskan satu ungkapan matematik untuk mengaitkan semua sumber haba dan komponen kerja dengan tenaga dalaman rumah mengikut Hukum Termodinamik Pertama ($\Delta U = \Delta Q + \Delta W$). Anda diingatkan bahawa arah aliran tenaga adalah penting.

[2 marks/markah]

[iv] What will happen to the system you just defined in [i] if eventually JK decided to open the window? Also briefly discuss the consequence of his action to your answer in [iii], such as any extra work and/or heat will be added/removed?

Apa yang akan berlaku kepada sistem yang anda tentukan dalam [i] sekiranya JK memutuskan untuk membuka tingkap rumahnya? Bincangkan secara ringkas apakah akibat tindakan beliau kepada jawapan anda di dalam [iii], adakah kerja tambahan dan/atau haba yang akan ditambah/dibuang?

[4 marks/markah]

2. [a] Compare the change in internal energy for the following two processes:

Bandingkan perubahan tenaga dalaman bagi dua proses berikut:

[i] Water is heated from its freezing point to its boiling point at 1 atm.
Air dipanaskan dari titik beku hingga takat didih pada 1 atm.

[ii] Saturated liquid water is vaporized at 1 atm.
Cecair tepu air mengewap pada 1 atm.

Hint: You need to use the saturated steam table provided in appendix.

Petunjuk: Anda perlu menggunakan jadual stim tepu yang disediakan dalam lampiran.

[5 marks/markah]

[b] Determine whether the following process violates the <u>first</u> and <u>second</u> laws of thermodynamics. An ideal gas of constant heat capacity (C_p = 50 kJ/kmol·K) at 5 bar and 400 K enters a device which is thermally and mechanically insulated from the surroundings. One-half of the gas leaves the device at 460 K and 1 bar, while the other half leaves at 300 K and 1 bar.

Tentukan sama ada proses berikut melanggar hukum termodinamik <u>pertama</u> dan <u>kedua</u>. Gas unggul dengan muatan haba malar (Cp = 50 kJ / mol • K) pada 5 bar dan 400 K memasuki satu alatan dengan penebatan haba dan mekanikal daripada persekitaran. Separuh daripada gas meninggalkan alatan ini pada 460 K dan 1 bar, manakala separuh lagi alatan ini pada 300 K dan 1 bar.

Given: For ideal gas $\Delta S = C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$

Diberi: Untuk gas unggul $\Delta S = C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$

[10 marks/markah]

[c] Develop expressions for isothermal changes in internal energy, enthalpy and entropy for a gas obeying the van der Waals equation of state.

Terbitkan ungkapan matematik untuk perubahan sesuhu dalam tenaga dalaman, entalpi dan entropi yang mematuhui persamaan keadaan van der Waals.

van der Waals EOS: $P = \frac{RT}{\overline{V} - b} - \frac{a}{\overline{V}^2}$

Given:
Diberi:

$$Tds = dU + Pd\overline{V}$$

$$\left(\frac{\partial U}{\partial \overline{V}}\right)_T = T\left(\frac{\partial s}{\partial \overline{V}}\right)_V - P$$

$$\left(\frac{\partial U}{\partial \overline{V}}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$$

[10 marks/markah]

3. [a] Briefly explain the difference between ideal vapor-compression refrigeration cycle and actual vapor-compression refrigeration cycle.

Terangkan dengan ringkas perbezaan antara kitaran penyejukan mampatan-wap unggul dan kitaran penyejukan mampatan-wap sebenar.

[5 marks/markah]

[b] Asuming a mixture of *n*-pentane and *n*-heptane is ideal, prepare vapor-liquid equilibrium diagrams for this mixture at

Andaikan satu campuran n-*petana dan* n-*heptana adalah unggul, sediakan gambarajah keseimbangan wap-cecair untuk campuran ini pada*

[i] A constant temperature of 50 °C
Suhu malar 50 °C

or
atau

[ii] A constant pressure of 1.013 bar
Tekanan malar 1.013 bar

Data:
Data:

$\ln P_5^{vap} = 10.422 - \frac{26799}{RT}$ and $\ln P_7^{vap} = 11.431 - \frac{35200}{RT}$

For P in bar, T in K, and R = 8.314 J/(mol K). The subscripts 5 and 7 designate pentane and heptanes, respectively.

P *dalam bar*, T *dalam* K *dan* R = *8.314 J/(mol K). Subskrip 5 dan 7 masing-masing merujuk kepada petana dan heptana.*

[10 marks/markah]

[c] Determine an expression for the fugacity of a pure gas from the van der Waals equation of state.

Tentukan ungkapan fugasiti untuk gas tulen dari persamaan keadaan van der Waals.

Given :
van der Waals equation: $P = \frac{RT}{v_i - b} - \frac{a}{v_i^2}$
fugacity of pure species: $G_i - G_i^o = \int_{P_{low}}^{P} v_i \, dP = RT ln\left[\frac{f_i^v}{P_{low}}\right]$

Diberi :
Persamaan van der Waals: $\mathrm{P} = \frac{\mathrm{RT}}{\mathrm{v_i - b}} - \frac{\mathrm{a}}{\mathrm{v_i^2}}$
Fugasiti untuk spesis tulen: $\mathrm{G_i - G_i^o} = \int_{\mathrm{P_{low}}}^{\mathrm{P}} \mathrm{v_i \, dP} = \mathrm{RTln}\left[\frac{\mathrm{f_i^v}}{\mathrm{P_{low}}}\right]$

[5 marks/markah]

[d] A mixture of 2 moles propane (1), 3 moles butane (2), and 5 moles pentane (3) is contained at 30 bar and 200 °C. The van der Waals constant for these species are:

Satu campuran 2 mol propana (1), 3 mol butana (2), dan 5 mol pentana (3) terkandung pada 30 bar dan 200 °C. Pemalar van der Waals untuk spesis-spesis tersebut adalah:

Species *Spesis*	a[J m^3/mol^2]	b[m^3/mol]
Propane *Propana*	0.94	9.06×10^{-5}
Butane *Butana*	1.45	1.22×10^{-4}
Pentane *Pentana*	1.91	1.45×10^{-4}

Determine the fugacity and fugacity coefficient of propane using the following approximation of Lewis fugacity rule.

Hitungkan fugasiti dan pekali fugasiti untuk propana mengikut anggaran aturan fugasiti Lewis.

[5 marks/markah]

4. [a] Briefly explain the following terms with one example:

Terangkan dengan ringkas terma-terma berikut bersama satu contoh:

[i] Liquefaction process
Proses pencecairan

[ii] Adiabatic expansion process
Proses pengembangan adiabatik

[iii] Isentropic expansion process
Proses pengembangan isentropik

[6 marks/markah]

[b] Explain how a heat pump operates during winter and summer.

Terangkan bagaimana satu pam haba beroperasi semasa musim panas dan sejuk.

[4 marks/markah]

[c] The following is a set of activity-coefficient data for a binary liquid system as determined from VLE data in Table Q.4.[c].:

Berikut adalah satu set data pekali-aktiviti untuk sistem penduaan cecair dari data VLE dalam Jadual S.4.[c].

Table Q.4.[c].
Jadual S.4.[c].

x_1	γ_1	γ_2
0.0523	1.202	1.002
0.1299	1.307	1.004
0.2233	1.295	1.006
0.2764	1.228	1.024
0.3482	1.234	1.022
0.4189	1.180	1.049
0.5001	1.129	1.092
0.5637	1.120	1.102
0.6469	1.076	1.170
0.7832	1.032	1.298
0.8576	1.016	1.393
0.9388	1.001	1.600
0.9813	1.003	1.404

Inspection of these experimental values suggests that they are *noisy*, but the question is whether they are *consistent*, and therefore possibly on average correct.

Pemeriksaan ke atas nilai-nilai eksperimen menunjukkan data ini hingar, tetapi terdapat persoalan sama ada ianya konsisten*, dan oleh itu berkemungkinan purata benar.*

[i] Find experimental values for G^E/RT and plot them along with the experimental values on ln γ_1 an ln γ_2 on a single graph.

Carikan nilai-nilai eksperimen untuk G^E/RT dan plot bersama nilai-nilai eksperimen pada ln γ_1 dan ln γ_2 atas satu graf.

[ii] Develop a valid correlation for the composition dependence of G^E/RT and show lines on the graph of part [a] that represent this correlation for all three of the quantities plotted there.

Bangunkan satu sekaitan sah untuk komposisi kebergantungan G^E/RT dan tunjukkan garisan pada graf bahagian [a] yang mewakili sekaitan untuk ketiga-tiga kuantiti yang diplot di situ.

[iii] Apply the consistency test to these data, and draw a conclusion with respect to this test.

Gunakan ujian konsistensi ke atas data tersebut, dan berikan satu kesimpulan untuk ujian ini.

[15 marks/markah]

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Appendix

The Thermodynamic Properties of Water and Steam[1]

THERMODYNAMIC PROPERTIES OF STEAM

Saturated Steam: Temperature Table

		Specific Volume		Internal Energy			Enthalpy			Entropy		
Temp (°C)	Press. (kPa)	Sat. Liquid	Sat. Vapor	Sat. Liquid	Evap.	Sat. Vapor	Sat. Liquid	Evap.	Sat. Vapor	Sat. Liquid	Evap.	Sat. Vapor
T	P	$\hat{V}^L$	$\hat{V}^V$	$\hat{U}^L$	$\Delta\hat{U}$	$\hat{U}^V$	$\hat{H}^L$	$\Delta\hat{H}$	$\hat{H}^V$	$\hat{S}^L$	$\Delta\hat{S}$	$\hat{S}^V$
0.01	0.6113	0.001 000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
5	0.8721	0.001 000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001 000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008
15	1.7051	0.001 001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	0.2245	8.5569	8.7814
20	2.339	0.001 002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	0.2966	8.3706	8.6672
25	3.169	0.001 003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	0.3674	8.1905	8.5580
30	4.246	0.001 004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	0.4369	8.0164	8.4533
35	5.628	0.001 006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	0.5053	7.8478	8.3531
40	7.384	0.001 008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	0.5725	7.6845	8.2570
45	9.593	0.001 010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	0.6387	7.5261	8.1648
50	12.349	0.001 012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	0.7038	7.3725	8.0763
55	15.758	0.001 015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	0.7679	7.2234	7.9913
60	19.940	0.001 017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	0.8312	7.0784	7.9096
65	25.03	0.001 020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	0.8935	6.9375	7.8310
70	31.19	0.001 023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	0.9549	6.8004	7.7553
75	38.58	0.001 026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001 029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001 033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001 036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001 040	1.982	397.88	2102.7	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159
	MPa											
100	0.101 35	0.001 044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
105	0.120 82	0.001 048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8	1.3630	5.9328	7.2958
110	0.143 27	0.001 052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5	1.4185	5.8202	7.2387
115	0.169 06	0.001 056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0	1.4734	5.7100	7.1833
120	0.198 53	0.001 060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3	1.5276	5.6020	7.1296
125	0.2321	0.001 065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
130	0.2701	0.001 070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5	1.6344	5.3925	7.0269

$\hat{V}$ [=] m^3/kg; $\hat{U}$, $\hat{H}$ [=] J/g = kJ/kg; $\hat{S}$ [=] kJ/kg K

[1]From G. J. Van Wylen and R. E. Sontag, *Fundamentals of Classical Thermodynamics, S. I. Version.* 2nd ed., John Wiley & Sons, New York (1978). Used with permission.