UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan TIGA 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 diguna pakai].

Answer ALL questions.

1. [a] At night, JK is using an air conditioner to cool down his room to 25 °C. If the air conditioner itself is consuming 500 W of electricity (so, $\dot{W}_{in} = 500\ W$) and the heat transfer rate between the room and its surrounding is given as $\dot{Q} = UA(T_{out} - T_{room})$ where U = 5 W/m^2·°C is the overall heat transfer coefficient and the A = 20 m^2 is area of contact between the room with outer ambient. Assume steady operating conditions are established,

[i] What is the temperature outside of the room?

[5 marks]

[ii] JK is using a fan to achieve same level of cooling as air conditioner. Both apparatus having the same energy efficiency. What is the maximum air outlet velocity from the fan if the air is discharged at 1.0 kg/s from JK's room?

[5 marks]

[b] Determine the specific volume of refrigerant-R134a at 1 MPa and 50 °C by using:

[i] ideal gas law.

[5 marks]

[ii] the generalized compressibility factor.

[6 marks]

[iii] Compare the values obtained by both methods to its actual value at 0.021796 m^3/kg and suggest which method is more accurate and justify your answer.

[4 marks]

2. [a] An automobile engine produces 100 kW on the output shaft with a thermal efficiency of 30%. The fuel it burns gives 35,000 kJ/kg as energy release. Find the total rate of energy rejected to the ambient and the rate of fuel consumption in kg/s.

[5 marks]

[b] A continuous stirred tank reactor CSTR as shown in Figure Q.2.[b] is used for conducting a polymerization reaction. Before the reaction start, the motor is turned on to promote the proper mixing of monomer precursor. Analyze this process, by taking (i) only CSTR, and, (ii) CSTR and motor as system by using First Law of Thermodynamics. Use your analysis to justify whether in both cases the internal energy gain is the same or not?

[10 marks]

Jawab SEMUA soalan.

1. [a] *Pada waktu malam, JK menggunakan penghawa dingin untuk menyejukkan biliknya hingga 25 °C. Jika penghawa dingin itu menggunakan 500 W elektrik ($\dot{W}_{in} = 500\ W$) dan kadar pemindahan haba antara bilik dan sekitarnya boleh ditentukan dengan persamaan ini $\dot{Q} = UA(T_{out} - T_{room})$ di mana U = 5 W/m^2·°C adalah pekali pemindahan haba keseluruhan dan A = 20 m^2 adalah luas permukaan hubungan antara bilik dengan persekitaran luar. Andaikan keadaan operasi yang stabil diwujudkan,*

   [i] *Apakah suhu di luar bilik?*

   [5 markah]

   [ii] *Jika JK menggunakan kipas angin untuk mencapai tahap penyejukan yang sama. Dengan menganggapkan kedua-dua alatan ini mempunyai kecekapan tenaga yang sama, apakah halaju keluaran udara maksimum daripada kipas ini sekiranya udara disalur keluar pada kadar 1.0 kg/s dari bilik JK?*

   [5 markah]

   [b] *Tentukan isipadu tentu penyejuk-R134a pada 1 MPa dan 50 °C, dengan:*

   [i] *hukum gas unggul.*

   [5 markah]

   [ii] *faktor kebolehmampatan umum.*

   [6 markah]

   [iii] *Bandingkan nilai yang diperolehi oleh kedua-dua kaedah ini dengan nilai sebenarnya pada 0.021796 m^3/kg dan cadangkan kaedah yang mana adalah lebih tepat dan jelaskan jawapan anda.*

   [4 markah]

2. [a] *Enjin kereta menghasilkan 100 kW kerja aci dengan kecekapan haba 30 %. Bahan api yang digunakan dapat membekalkan 35,000 kJ/kg tenaga. Carikan jumlah kadar tenaga penolakan ke sekitar dan kadar penggunaan bahan api dalam unit kg/s.*

   [5 markah]

   [b] *Sebuah reaktor tangki teraduk berterusan CSTR seperti ditunjukkan dalam Rajah S.2.[b] telah digunakan untuk tindak balas pempolimeran. Sebelum tindak balas bermula, reaktor, motor pengacau dihidupkan untuk menggalakkan pencampuran pelopor monomer. Analisa proses ini dengan mengambil (i) hanya CSTR, dan, (ii) CSTR bersama motor sebagai sistem berdasarkan Hukum Termodinamik Pertama. Gunakan analisis anda untuk tentukan sama ada kenaikan tenaga dalaman adalah sama ataupun tidak?*

   [10 markah]

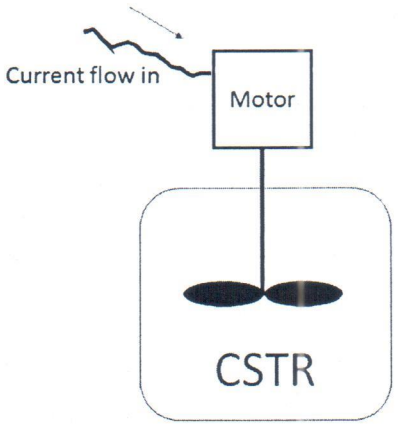


Figure Q.2.[b]

[c] JK heats up an iron bar to 750 K and allows it to cool down in two different rooms at temperature (i) 600 K and (ii) 323 K. If the energy loss from iron bar in both processes is 1800 kJ, determine which heat transfer process is more irreversible? Relate your calculation to the temperature difference.

[10 marks]

3. A refrigeration process with interstage cooling uses refrigerant-R134a. The outlet of the condenser is to be saturated liquid at 40 °C. The evaporator is to operate at -20 °C, and the outlet is saturated vapor. The economizer is to operate at 10 °C. The schematic of the process is shown in Figure Q.3. Create a table listing all streams from low to high stream numbers. Fill in the table as you complete the problem sections. Attach the *P-H* diagram with your solution.

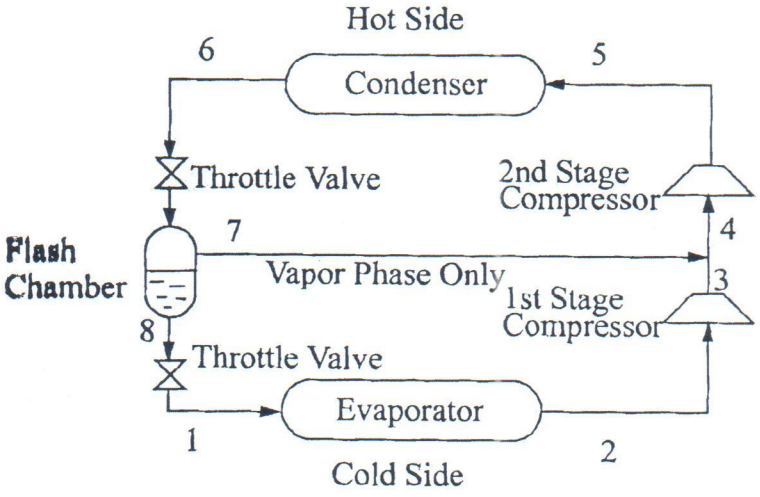
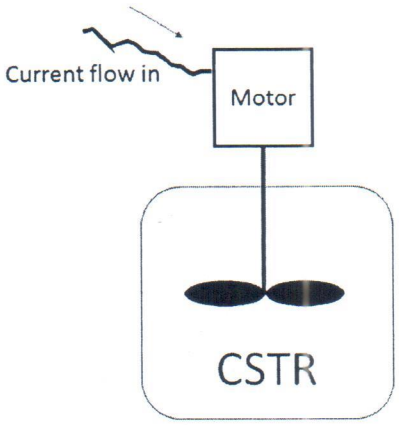


Figure Q.3

[a] Determine the required flowrate of stream 1 if the cooling capacity of the unit is 8250 kJ/h.

[5 marks]

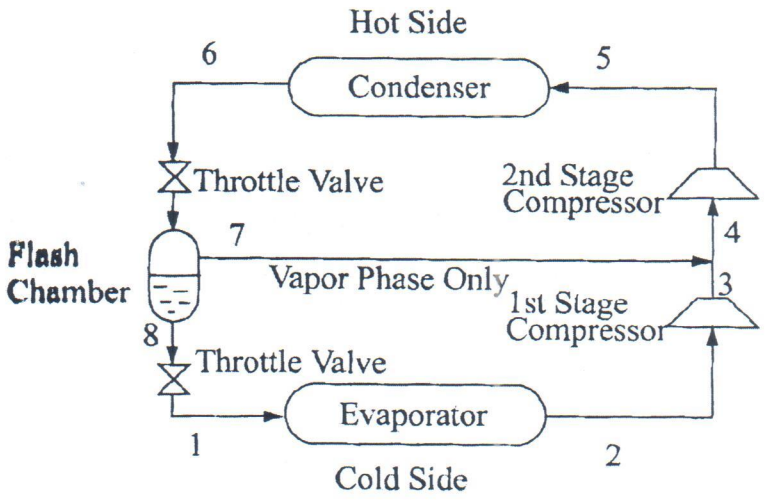


Rajah S.2.[b]

[c] *JK memanaskan seketul palang besi hingga 750 K dan dibiarkan untuk penyejukkan dalam dua bilik dengan suhu yang berbeza pada (i) 600 K dan (ii) 323 K. Jika kehilangan tenaga dari palang besi dalam kedua-dua proses ini ialah 1800 kJ, tentukan proses pemindahan haba yang manakah lebih tak berbalik? Kaitkan pengiraan anda dengan perbezaan suhu.*

[10 markah]

3. *Suatu proses penyejukan dengan penyejuk antara peringkat menggunakan bahan pendingin R134a. Alur keluar pemeluwap adalah cecair tepu pada 40 °C. Penyejat beroperasi pada -20 °C, dan alur keluarnya adalah wap tepu. Penjimat beroperasi pada 10 °C. Skema proses ditunjukkan dalam Rajah S.3. Sediakan satu jadual senarai semua arus dari nombor rendah hingga tinggi. Isikan jadual senarai tersebut apabila penyelesaian untuk setiap seksyen disiapkan. Sertakan gambarajah P-H bersama jawapan anda.*



Rajah S.3

[a] Hitungkan kadar aliran arus 1 yang diperlukan jika kapasiti penyejukkan adalah 8250 kJ/jam.

[5 markah]

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[b] Determine the pressure of stream 3, and the work required by the first stage compressor if it has an efficiency of 85 %.

[5 marks]

[c] What are the flowrates of stream 6 and 7?

[5 marks]

[d] What is the enthalpy of stream 4?

[5 marks]

[e] Determine the work required by the second stage compressor (85 % efficient) and the coefficient of performance.

[5 marks]

4. [a] Discuss briefly the term equilibrium in VLE.

[5 marks]

[b] Define Raoult's law and discuss briefly the two major assumptions required to reduce VLE calculations .

[5 marks]

[c] Define Henry's law and discuss briefly its difference compared to Raoult's law.

[5 marks]

[d] At constant temperature,

$$\Delta G = RTln(f_2/f_1) = \Delta H - T\Delta S.$$

If state 1 is at low pressure where the gas is ideal, then

$$f_1 = P_1, RTln(f_2/P_1) = \Delta H - T\Delta S,$$

Use this method to determine the fugacity of steam at 400 °C and 15 MPa. Calculate the fugacity coefficient at this condition?

[10 marks]

[b] *Hitungkan tekanan arus 3, dan kerja yang diperlukan oleh pemampat tingkat pertama jika ia mempunyai 85 % kecekapan.*

[5 markah]

[c] *Apakah kadar aliran arus 6 dan 7?*

[5 markah]

[d] *Apakah entalpi arus 4?*

[5 markah]

[e] *Tentukan kerja yang diperlukan oleh pemampat tingkat kedua (85 % kecekapan) dan pekali prestasinya.*

[5 markah]

4. [a] *Bincangkan dengan ringkas sebutan keseimbangan dalam VLE.*

[5 markah]

[b] *Takrifkan hukum Raoult dan bincangkan dengan ringkas dua andaian utama yang diperlukan untuk mengurangkan pengiraan VLE.*

[5 markah]

[c] *Takrifkan hukum Henry dan bincangkan dengan ringkas perbezaanya dibandingkan dengan hukum Raoult.*

[5 markah]

[d] *Pada suhu malar,*

$$\Delta G = RTln(f_2/f_1) = \Delta H - T\Delta S.$$

Jika keadaan 1 adalah pada tekanan rendah di mana gas adalah unggul, maka

$$f_1 = P_1, RTln(f_2/P_1) = \Delta H - T\Delta S,$$

Guna kaedah ini untuk menghitung fugasiti stim pada 400 °C dan 15 MPa. Kirakan pekali fugasiti pada keadaan ini?

[10 markah]

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Appendix

TABLE A–1

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, M kg/kmol	Gas constant, R kJ/kg·K*	*Critical-point properties* Temperature, K	Pressure, MPa	Volume, m^3/kmol
Air	—	28.97	0.2870	132.5	3.77	0.0883
Ammonia	NH_3	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Benzene	C_6H_6	78.115	0.1064	562	4.92	0.2603
Bromine	Br_2	159.808	0.0520	584	10.34	0.1355
n-Butane	C_4H_{10}	58.124	0.1430	425.2	3.80	0.2547
Carbon dioxide	CO_2	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Carbon tetrachloride	CCl_4	153.82	0.05405	556.4	4.56	0.2759
Chlorine	Cl_2	70.906	0.1173	417	7.71	0.1242
Chloroform	$CHCl_3$	119.38	0.06964	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl_2F_2	120.91	0.06876	384.7	4.01	0.2179
Dichlorofluoromethane (R-21)	$CHCl_2F$	102.92	0.08078	451.7	5.17	0.1973
Ethane	C_2H_6	30.070	0.2765	305.5	4.48	0.1480
Ethyl alcohol	C_2H_5OH	46.07	0.1805	516	6.38	0.1673
Ethylene	C_2H_4	28.054	0.2964	282.4	5.12	0.1242
Helium	He	4.003	2.0769	5.3	0.23	0.0578
n-Hexane	C_6H_{14}	86.179	0.09647	507.9	3.03	0.3677
Hydrogen (normal)	H_2	2.016	4.1240	33.3	1.30	0.0649
Krypton	Kr	83.80	0.09921	209.4	5.50	0.0924
Methane	CH_4	16.043	0.5182	191.1	4.64	0.0993
Methyl alcohol	CH_3OH	32.042	0.2595	513.2	7.95	0.1180
Methyl chloride	CH_3Cl	50.488	0.1647	416.3	6.68	0.1430
Neon	Ne	20.183	0.4119	44.5	2.73	0.0417
Nitrogen	N_2	28.013	0.2968	126.2	3.39	0.0899
Nitrous oxide	N_2O	44.013	0.1889	309.7	7.27	0.0961
Oxygen	O_2	31.999	0.2598	154.8	5.08	0.0780
Propane	C_3H_8	44.097	0.1885	370	4.26	0.1998
Propylene	C_3H_6	42.081	0.1976	365	4.62	0.1810
Sulfur dioxide	SO_2	64.063	0.1298	430.7	7.88	0.1217
Tetrafluoroethane (R-134a)	CF_3CH_2F	102.03	0.08149	374.2	4.059	0.1993
Trichlorofluoromethane (R-11)	CCl_3F	137.37	0.06052	471.2	4.38	0.2478
Water	H_2O	18.015	0.4615	647.1	22.06	0.0560
Xenon	Xe	131.30	0.06332	289.8	5.88	0.1186

*The unit kJ/kg·K is equivalent to kPa·m^3/kg·K. The gas constant is calculated from $R = R_u/M$, where R_u = 8.31447 kJ/kmol·K and M is the molar mass.

Source: K. A. Kobe and R. E. Lynn, Jr., *Chemical Review* 52 (1953), pp. 117–236; and ASHRAE, *Handbook of Fundamentals* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1993), pp. 16.4 and 36.1.

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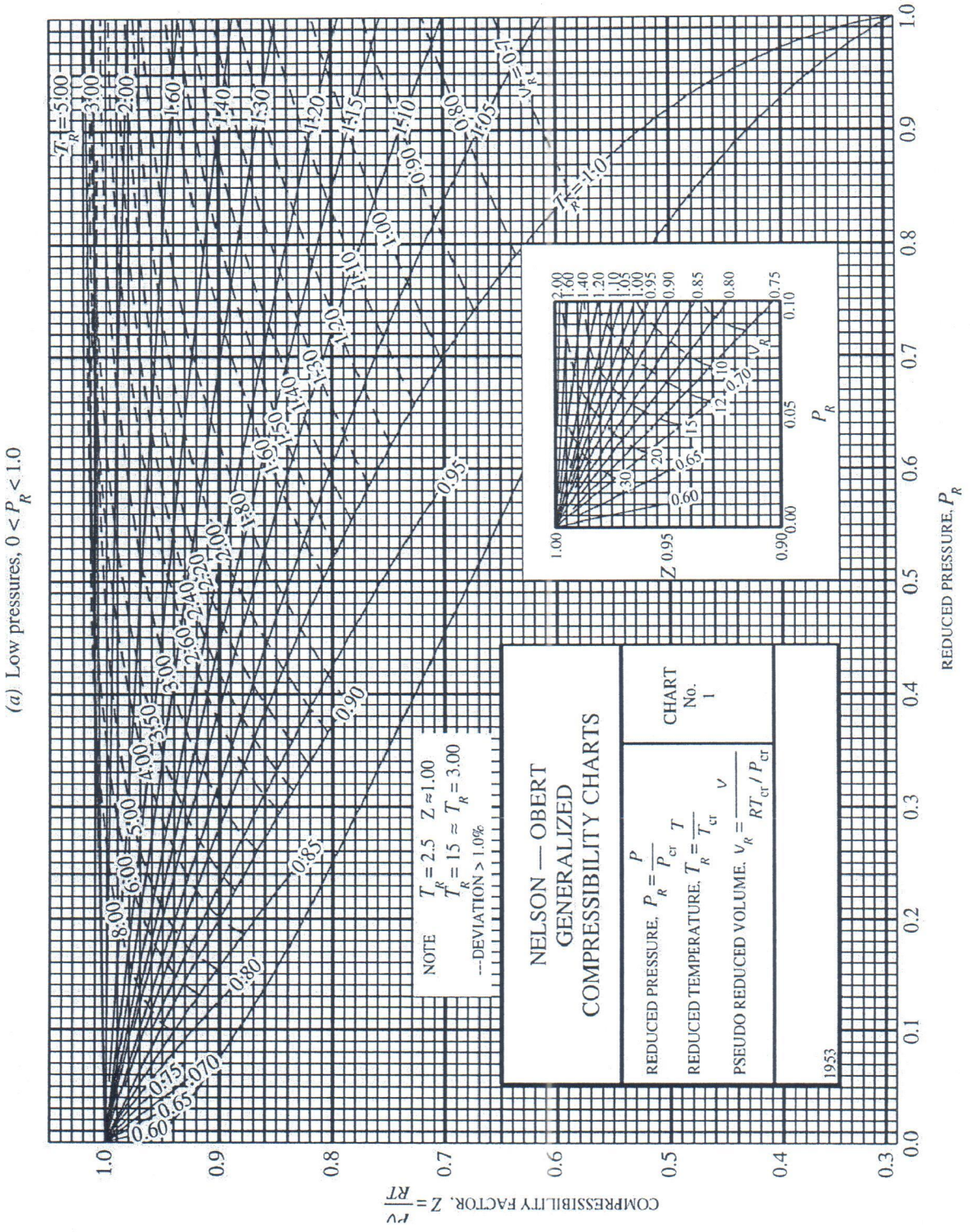
(a) Low pressures, $0 < P_R < 1.0$
NELSON — OBERT
GENERALIZED
COMPRESSIBILITY CHARTS
CHART
No.
1
REDUCED PRESSURE, $P_R = \frac{P}{P_{cr}}$
REDUCED TEMPERATURE, $T_R = \frac{T}{T_{cr}}$
PSEUDO REDUCED VOLUME, $v_R = \frac{v}{RT_{cr}/P_{cr}}$
1953
NOTE $T_R = 2.5$ $Z \approx 1.00$
$T_R = 1.5 \approx T_R = 3.00$
---DEVIATION > 1.0%
COMPRESSIBILITY FACTOR, $Z = \frac{Pv}{RT}$
REDUCED PRESSURE, P_R

E.12 PRESSURE-ENTHALPY DIAGRAM FOR R134A (1,1,1,2-TETRAFLOUROETHANE)

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