UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2016/2017 Academic Session

June 2017

EKC 463 – Advanced Process Safety Engineering
[Kejuruteraan Keselamatan Proses Lanjutan]

Duration : 3 hours
[Masa : 3 jam]

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

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

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) 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] [i] Define what is a system.

[3 marks]

[ii] Discuss the characteristics of a system.

[10 marks]

[b] A hydrocarbon processing plant consisted of two reactors which shared a product receiver tank. The product receiver tank could be by-passed by the dotted lines to empty the reactors when they were being shutdown as shown in Figure Q.1.[b].

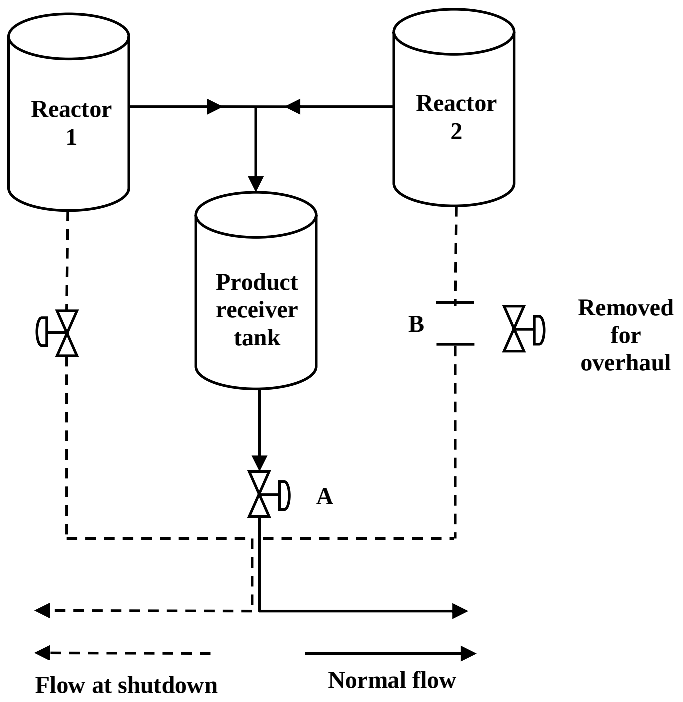


Figure Q.1.[b] Simplified process flow diagram

When the Reactor 2 shutdown, Valve *B* was removed for overhaul. The pipe line to connect Valve *B* should have been isolated by slip-plates but unfortunately one of the interconnecting lines was overlooked. A few hours later valve A was operated remotely from the control room. There were no windows and the operator could not see the plant. He heard the evacuation alarm sound but he did not know the reason soon the hot hydrocarbon travelled in the wrong direction and came out from the open end through the by-pass line. Two men were killed and several seriously injured due to a leak of 4 tones of hot flammable hydrocarbon.

[i] Describe the type of errors occurred that lead to the leak of hydrocarbon.

[6 marks]

[ii] Suggest methods to prevent the above incident.

[6 marks]

Jawab SEMUA soalan.

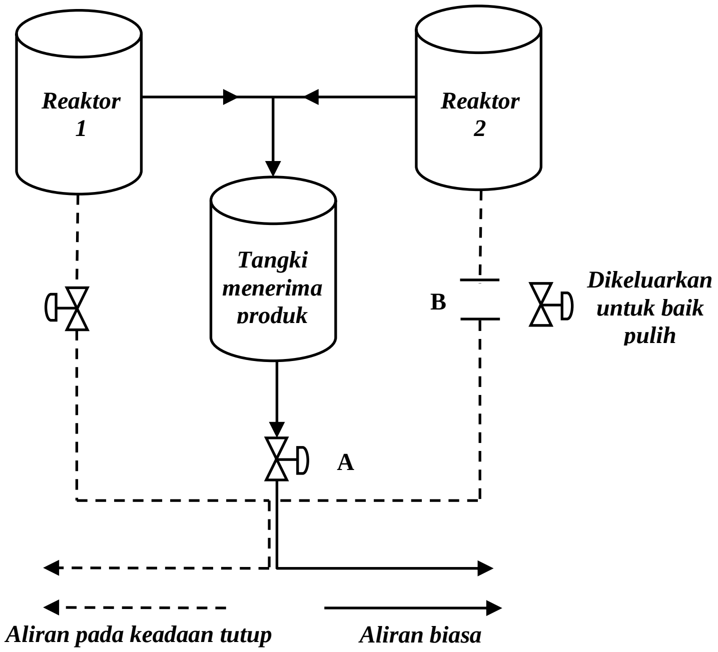
1. [a] [i] *Takrifkan apa itu sistem.*

[3 markah]

[ii] *Bincangkan ciri-ciri satu sistem.*

[10 markah]

[b] *Sebuah loji pemprosesan hidrokarban mengandungi dua reaktor yang berkongsi dengan sebuah tangki penerima produk. Tangki penerima produk boleh dipirau melalui garis putus-putus untuk mengosongkan reaktor-reaktor ketika ia dalam keadaan tutup seperti yang ditunjukan dalam Rajah S.1.[b].*



Rajah S.1.[b] Gambarajah aliran proses ringkas

Apabila Reaktor 2 berada dalam keadaan tutup, Injap B *ditanggalkan untuk baik pulih. Talian paip yang menyambungkan Injap* B *sepatutnya diasingkan oleh plat-gelincir tetapi malangnya salah satu talian penyambungan telah terlepas pandang. Selepas beberapa jam, injap A dikendalikan jauh dari bilik kawalan. Tiada tingkap dan operator tidak dapat melihat loji tersebut. Beliau mendengar suara penggera pengungsian tetapi tidak mengetahui puncanya, tidak lama kemudian hidrokarbon panas mengalir ke arah yang salah dan keluar melalui talian pirau. Dua orang maut dan beberapa cedera parah akibat kebocoran 4 tan hidrokarbon panas mudah terbakar.*

[i] *Bincangkan ralat-ralat yang telah berlaku menyebabkan kebocoran hidrokarbon.*

[6 markah]

[ii] *Berikan beberapa cadangan untuk mengelakkan insiden di atas.*

[6 markah]

2. [a] List down four types of failure rate data.

[4 marks]

[b] [i] A centrifugal pump used in a continuous process has a constant failure rate λ, 3.82×10^{-4} h^{-1}. Compute the reliability of that pump if it is operated for 24 h per day and 300 days per year. Then, give two factors which could influence the pump failure rate.

[5 marks]

[ii] A plant consists of five (5) identical pumps of which at least 3 must function properly for the system to success. If each pump has a reliability of 0.96, determine the reliability of that system.

[6 marks]

[c] A system has four (4) components with the reliabilities as shown below :

$$R_1 = 0.97,\ R_2 = 0.99,\ R_3 = R_4 = 0.98$$

Propose a suitable system by sketching its block diagram and find the system reliability if :

[i] Four (4) components must work for a system to success.

[3 marks]

[ii] Components 1, 2 and either component 3 or 4 must work for a system to success.

[5 marks]

[iii] Comment on results in Q.2.[c].[i] and [ii].

[2 marks]

2. [a] *Senaraikan empat jenis data kadar kegagalan.*

[4 markah]

[b] [i] *Satu pam empar digunakan untuk proses berterusan mempunyai kadar kegagalan tetap* λ, *3.82 × 10*$^{-4}$ *j*$^{-1}$. *Hitungkan kebolehpercayaan untuk pam tersebut jika ia beroperasi selama 24 j sehari dan 300 hari setahun. Kemudian, beri dua faktor yang boleh mempengaruhi kadar kegagalan pam tersebut.*

[5 markah]

[ii] *Sebuah loji mengandungi lima (5) pam yang serupa di mana sekurang-kurangnya 3 mesti berfungi dengan baik untuk menjayakan sistem. Jika setiap pam berkebolehpercayaan 0.96, hitungkan kebolehpercayaan sistem tersebut.*

[6 markah]

[c] *Satu sistem mengandungi empat (4) komponen yang kebolehpercayaannya ditunjukkan seperti di bawah :*

$R_1 = 0.97$, $R_2 = 0.99$, $R_3=R_4=0.98$

Cadangkan satu sistem yang sesuai dengan melakar gambarajah blok dan hitungkan kebolehpercayaan sistem jika :

[i] *Empat (4) komponen mesti berfungsi untuk menjayakan sistem.*

[3 markah]

[ii] *Komponen 1, 2 dan sama ada komponen 3 atau 4 mesti berfungsi untuk menjayakan sistem.*

[5 markah]

[iii] *Komen keputusan di S.2.[c].[i] dan [ii].*

[2 markah]

3. An explosion occurred in XYZ industry. Based on the investigation, it was believed that ten thousands (10,000) kg of *LPG* was released due to operator error. The accident had caused several fatalities and destruction to the surrounding buildings. As newly appointed Chemical Engineer, you are asked by the board of directors to get involved in the investigation particularly to conduct the quantitative risk assessment for future planning.

Data:

Ambient temperature	298 K
Heat of combustion of LPG	50,000 kJ/kg
TNT equivalent energy	4686 kJ/kg
Explosion efficiency	5 %

[a] Determine the distances for a person to experience peak overpressures (P^o) of 226.05 kPa, 144.54 kPa and 70.10 kPa, respectively.

[15 marks]

[b] Perform probit analysis to determine the percentage of fatalities of the peak overpressure received in part [a].

[7 marks]

[c] Determine the individual risks at the three locations (50 m, 500 m and 1000 m) by assuming the incident frequency of 2.5×10^{-4}/yr.

[3 marks]

4. [a] What do you understand by the term flare?

[3 marks]

[b] With the aid of sketches, discuss in detail the two types of flare that are commonly used in industries.

[10 marks]

[c] Discuss in details three (3) factors which can influence flare system design.

[12 marks]

3. *Suatu letupan telah berlaku di industri XYZ. Berdasarkan siasatan, dipercayai sebanyak sepuluh ribu kilogram (10,000)* LPG *telah terbebas disebabkan kesilapan operator. Kemalangan itu telah mengakibatkan beberapa kematian dan kemusnahan kepada bangunan sekitar. Sebagai seorang Jurutera Kimia yang baru dilantik, anda diarahkan oleh pihak lembaga pengarah untuk turut terlibat dalam siasatan tersebut terutama sekali untuk melakukan penilaian risiko secara kuantitatif bagi perancangan pada masa akan datang.*

Data:

Suhu ambien	*298 K*
Haba pembakaran LPG	*50,000 kJ/kg*
Tenaga setara TNT	*4686 kJ/kg*
Kecekapan letupan	*5 %*

[a] Tentukan jarak-jarak bagi seorang itu mengalami tekanan lebihan puncak (P^o) masing-masing 226.05 kPa, 144.54 kPa dan 70.10 kPa.

[15 markah]

[b] Laksanakan analisa probit bagi menentukan peratus kematian pada setiap tekanan lebihan puncak yang diterima dalam bahagian [a].

[7 markah]

[c] Tentukan risiko individu bagi tiga tempat (50 m, 100 m dan 1000 m) dengan mengandaikan frekuensi kemalangan 2.5×10^{-4}/setahun.

[3 markah]

4. *[a] Apakah yang anda faham dengan suar?*

[3 markah]

[b] Dengan berbantukan lakaran, bincangkan dengan terperinci kedua-dua jenis suar yang selalu digunakan di industri.

[10 markah]

[c] Bincangkan dengan terperinci tiga (3) faktor yang mempengaruhi rekabentuk sistem suar.

[12 markah]

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Appendix

Equations related to reliability

$$\mathbf{R(t)} = \mathbf{e}^{-\lambda t}$$

$$\mathbf{R(t)} = \mathbf{e}^{-(t/\alpha)^{*}\beta}$$

$$\mathbf{Fr(t)} = \left(\beta/\alpha^{\beta}\right)(t)^{\beta-1}$$

$$\lambda_A = \lambda_B \prod_{i=1}^{n} f_i$$

$$R_s = \prod_{i=1}^{m} R_i \qquad R_s = R_1 \times R_2 \times R_3 \times .....R_m$$

$$R_s = 1 - \sum_{i=1}^{m}(1 - R_i) \qquad R_s = 1 - m(1 - R)$$

$$\begin{aligned} R_p &= 1 - F_p \\ &= 1 - \prod_{i=1}^{m} F_i \\ &= 1 - (1 - R_1)(1 - R_2)......(1 - R_m) \end{aligned} \qquad R_p = 1 - (1 - R)^m$$

$$R_{sp} = [1 - (1 - R)^k]^m \qquad R_{ps} = 1 - \left(1 - R^k\right)^m$$

$$R_{k/m} = \sum_{i=k}^{m} \binom{m}{i} R^i (1 - R)^{m-i}$$

where

$$\binom{m}{i} = \frac{m!}{(m - i)!\, i!}$$

$R_{k/m}$ = k-out-of-m network/system reliability

Useful Equations

$$C(t) = \frac{qL}{vH}\left(1 - e^{(-vt/L)}\right)$$

$$C(x, y, z) = \frac{q}{2\pi\sigma_y\sigma_z v} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

$$\Delta H = \frac{2v_s r_s}{v}\left[1.5 + 2.68 \times 10^{-2} P\left(\frac{T_s - T_a}{T_s}\right) 2r_s\right]$$

Flare Design:

$$M_a = 11.61 \times 10^{-2} \frac{W}{Pd^2}\sqrt{\frac{T}{kM}}$$

Unit: W= kg/s, P= kPa, d = m, T= Kelvin

$$H_f = -60d_f + 0.5\sqrt{(120d_f)^2 - \left(\frac{4\pi q_f X_f^2 - 960Q_m\sqrt{M}}{\pi q_f}\right)}$$

Unit H_f = ft, d_f = ft, q_f = Btu/hr/ft^2 , X_f= ft, Q_m lb/hr

Probit Analysis:

Thermal Radiation: $Y = -14.9 + 2.56\ In\left(\frac{20\ I^{\frac{4}{3}}}{10^4}\right)$, I is Thermal radiation (W/m^2)

Explosion: $Y = -77.1 + 6.91\ln(P^o)$ where P^o is peak overpressure (Pa)

Source Model	Dispersion Models
$\frac{P_2 - P_1}{\rho} + \frac{g}{g_c}(z_2 - z_1) + \frac{1}{2g_c}(v_2^2 - v_1^2) + \sum e_f + \frac{W_s}{\dot{m}} = 0$ $e_f = K_f\left(\frac{v^2}{2g_c}\right)$ $K_f = \frac{K_1}{N_{RE}} + K_\infty\left(1 + \frac{1}{ID_{inches}}\right)$ $\dot{m} = AC_D\sqrt{2\rho g_c(P_1 - P_2)}$ $\dot{m} = \rho vA = \rho AC_D\sqrt{2\left(\frac{g_c P_g}{\rho} + gh_L\right)}$ $Q_m = C_D AP_o\sqrt{\left(\frac{2g_c M}{R_g T_o}\frac{\gamma}{\gamma - 1}\right)\left[\left(\frac{P}{P_o}\right)^{2/\gamma} - \left(\frac{P}{P_o}\right)^{(\gamma+1)/\gamma}\right]}$ $\frac{P_{choked}}{P_o} = \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)}$ $(Q_m)_{choked} = C_D AP_o\sqrt{\left(\frac{g_c M\gamma}{R_g T_o}\right)\left[\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)}\right]}$	$\langle C\rangle_{\max} = \frac{\dot{m}}{\pi\sigma_y\sigma_z u}$ $\langle C\rangle_{ppm} = \frac{\dot{m}}{\pi\sigma_y\sigma_z u}\left[\frac{RT}{MP}\times 10^6\right]$ $\sigma_y = \exp\left[4.23 + 0.9222\ln\left(\frac{x}{1000}\right) - 0.0087\left[\ln\left(\frac{x}{1000}\right)\right]^2\right]$ $\sigma_z = \exp\left[3.414 + 0.7371\ln\left(\frac{x}{1000}\right) - 0.0316\left[\ln\left(\frac{x}{1000}\right)\right]^2\right]$

Equations related to Fire Modeling	Equations related to Explosion Modeling
Pool Fires: $\dot{y}_{max} = 1.27 \times 10^{-6} \dfrac{\Delta H_c}{\Delta H^*}$ $\Delta H^* = \Delta H_v + \int_{T_a}^{T_{BP}} C_p dT$ $m_B = 1 \times 10^{-3} \dfrac{\Delta H_c}{\Delta H^*}$ $D_{max} = 2\sqrt{\dfrac{\dot{V}_L}{\pi \dot{y}}}$ $\dfrac{H}{D} = 42\left(\dfrac{m_B}{\rho_a \sqrt{gD}}\right)^{0.61}$ $E_{av} = E_m e^{-SD} + E_s\left(1 - e^{-SD}\right)$ $F_P = \dfrac{1}{4\pi x^2}$ $\tau_a = 2.02\left(P_W X_S\right)^{-0.09}$ $P_{w(atm)} = \dfrac{RH}{100} \exp\left[14.4114 - \dfrac{5328}{T_{a(K)}}\right]$ $E_r = \tau_a Q_r F_P = \tau_a \eta m_B \Delta H_c A F_P$ **Jet Fires:** $\dfrac{L}{d_j} = \dfrac{5.3}{C_T}\sqrt{\dfrac{T_f / T_j \left[C_T + \left(1 - C_T\right)\dfrac{M_a}{M_f}\right]}{\alpha_T}}$ $E_r = \tau_a Q_r F_p = \tau_a \eta \dot{m} \Delta H_c F_P$	**TNT Model** $W = \dfrac{\eta M E_c}{E_{TNT}}$ $Z_e = \dfrac{R}{(M_{TNT})^{1/3}}$ $P_S = \dfrac{P_o}{P_a}$ TNO Model $\bar{R} = \dfrac{R}{\left(E/P_o\right)^{1/3}}$ $P_s = \Delta \bar{P}_s . P_o$ $t_+ = \bar{t}_+ \left[\dfrac{\left(E/P_o\right)^{1/3}}{c_o}\right]$

Table Transformation from Percentages to Probits[1]

%	0	1	2	3	4	5	6	7	8	9
0	—	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
%	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

[1] D. J. Finney, *Probit Analysis*, (Cambridge: Cambridge University Press, 1971), p. 25. Reprinted by permission.

Volume Equivalents

in^3	ft^3	US gal	L	m^3
1	5.787×10^{-4}	4.329×10^{-3}	1.639×10^{-2}	1.639×10^{-5}
1728	1	7.481	28.32	2.832×10^{-2}
231	0.1337	1	3.785	3.785×10^{-3}
61.03	3.531×10^{-2}	0.2642	1	1.000×10^{-3}
6.102×10^4	35.31	264.2	1000	1

Ideal Gas Constant R_g

1.9872 cal/g-mol K
1.9872 Btu/lb-mol°R
10.731 psia ft³/lb-mol°R
8.3143 kPa m³/kg-mol K = 8.314 J/g-mol K
82.057 cm³ atm/g-mol K = 8.2057×10^{-5} m³ atm/mol K
0.082057 L atm/g-mol K = 0.082057 m³ atm/kg-mol K
21.9 (in Hg) ft³/lb-mol°R
0.7302 ft³ atm/lb-mol°R
1,545.3 ft lb_f/lb-mol°R

Gravitational Constant, g_c

32.174 ft-lb_m/lb_f-s²
1 (kg m/s²)/N
1 (g cm/s²)/dyne

Miscellaneous

1 Poise = 100 centipoise = 0.1 kg/m s = 0.1 Pa s = 0.1 N s/m²
1 N = 1 kg m/s²
1 J = 1 N m = 1 kg m²/s²
1 centipoise = 1×10^{-3} kg/m s = 2.4191 lb/ft-hr = 6.7197×10^{-4} lb/ft s

$$\frac{p_o}{p_a} = \frac{1616\left[1 + \left(\frac{z_e}{4.5}\right)^2\right]}{\sqrt{1 + \left(\frac{z_e}{0.048}\right)^2}\sqrt{1 + \left(\frac{z_e}{0.32}\right)^2}\sqrt{1 + \left(\frac{z_e}{1.35}\right)^2}}. \tag{6-23}$$