
UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

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

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains ELEVEN printed pages and FOUR printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEBELAS muka surat yang bercetak dan EMPAT 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] [i] Briefly explain the 3 main factors that lead to human error in the human factors theory. [6 marks]
- [ii] Discuss the most important elements in implementing a system safety program. [4 marks]
- [iii] What are the main purposes of the system safety audit program? [3 marks]

[b] Figure Q.1.[b] shows the layout of the relevant pipework of a process system in a plant. In the original design, the pump seals were supplied with water via valve *A*. However, the water pressure varied. In order to provide a more consistent supply, a small head tank was installed and the old supply line to the pump seals was then used as the drain line. During construction, the contractor failed to disconnect the pump seals.

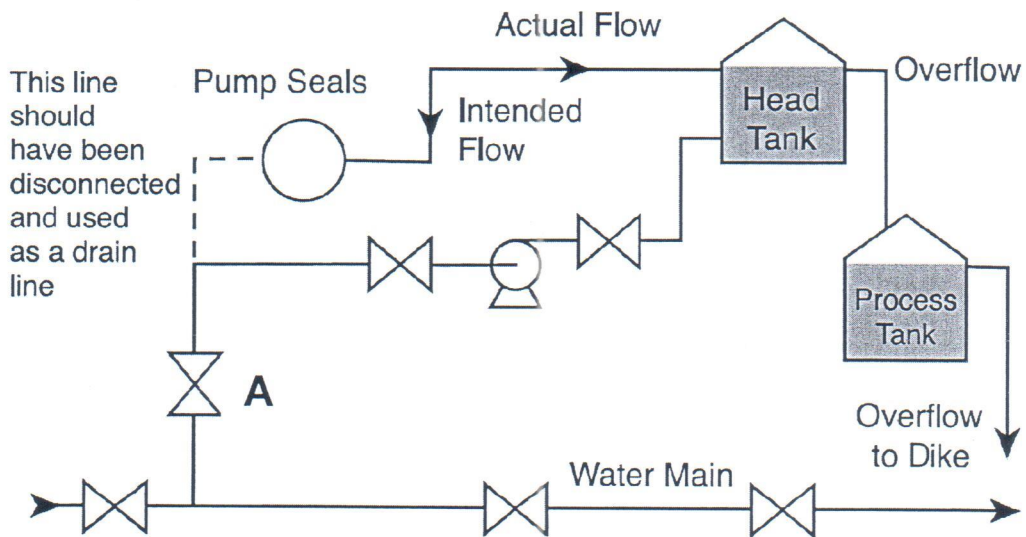


Figure Q.1.[b].

Once the construction completed, valves *A* was opened for an hour to supply water to the head tank. Water flowed in the opposite direction to that intended and into the head tank. The head tank did not overflow directly into the dike but into another process tank that contained process material. Although the high-level alarm in the dike sounded but nobody heard it. Then, the process tank overflowed, so a spillage of water has turned into a spillage of process liquid.

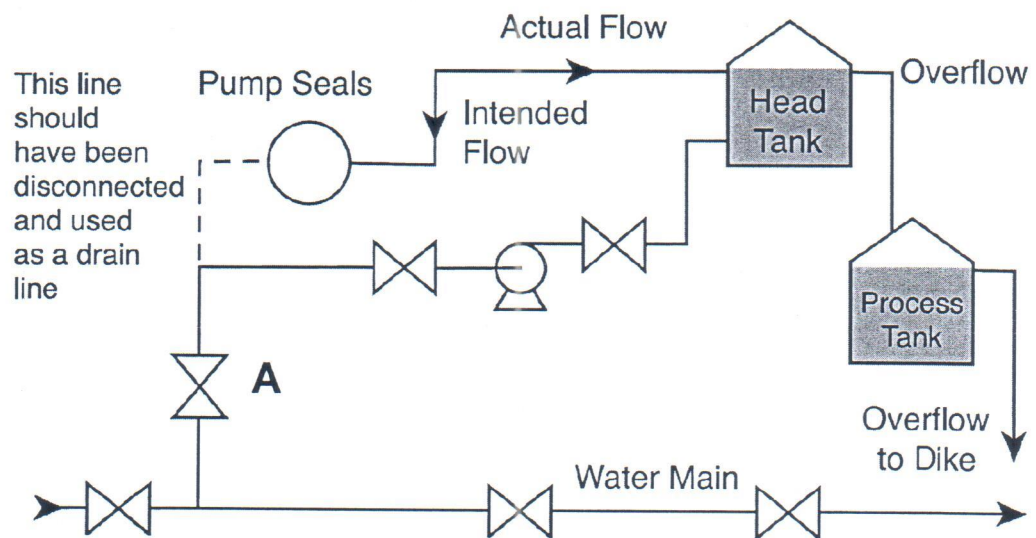
- [i] Describe the type of errors occurred that lead to the spillage.
- [ii] Suggest methods to prevent the above incident.

[12 marks]

Jawab SEMUA soalan.

- 1. [a] [i] Terangkan secara ringkas 3 faktor utama yang menyebabkan kesilapan manusia dalam teori faktor manusia. [6 markah]
- [ii] Bincangkan elemen-elemen yang utama dalam melaksanakan program keselamatan sistem. [4 markah]
- [iii] Apakah tujuan-tujuan utama program audit keselamatan sistem? [3 markah]

[b] Rajah S.1.[b] menunjukkan susun atur paip bagi satu sistem proses dalam loji. Dalam reka bentuk asal, pam kedap dibekalkan dengan air melalui injap A. Walau bagaimanapun, tekanan air utama berbeza. Bagi memastikan bekalan yang lebih konsisten, satu tangki turus kecil telah dipasang dan saluran bekalan lama untuk pam kedap digunakan sebagai saluran penyaliran. Semasa pembinaan, kontraktor telah gagal untuk memutuskan penyambungan pam kedap.



Rajah S.1.[b]

Setelah tamat pembinaan, injap A telah dibuka selama satu jam untuk membekalkan air ke tangki turus. Air mengalir dalam arah yang bertentangan seperti yang dikehendaki lalu memasuki ke tangki turus. Tangki turus tidak terus melimpah ke parit tetapi ke dalam tangki proses lain yang mengandungi cecair proses. Walaupun penggera peringkat tinggi pada parit tersebut berbunyi tetapi tiada sesiapa pun yang mendengarnya. Kemudian, tangki proses melimpah, menyebabkan tumpahan air tersebut telah bertukar menjadi tumpahan cecair proses.

- [i] Terangkan jenis kesalahan-kesalahan yang berlaku lalu menyebabkan tumpahan.
- [ii] Beri cadangan kaedah-kaedah untuk mencegah kejadian tersebut.

[12 markah]

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2. [a] Define the following terms:

[i] System

[2 marks]

[ii] Reliability

[2 marks]

[iii] Redundancy

[2 marks]

[b] What is the difference between the predicted data and judgmental data?

[3 marks]

[c] A system consists of 5 independent pumps in series, each having a reliability of 0.98.

[i] Calculate the reliability of the system.

[3 marks]

[ii] Determine the system reliability if the similar pumps are increased to 10 units in series.

[3 marks]

[iii] What would be the reliability of each pump in the 10 units in series system if we want to maintain the same system reliability as part [i]?

[4 marks]

[d] Derive a general expression for the reliability of the model shown in Figure Q.2.[d] and hence evaluate the system reliability if all components have a reliability of 0.9.

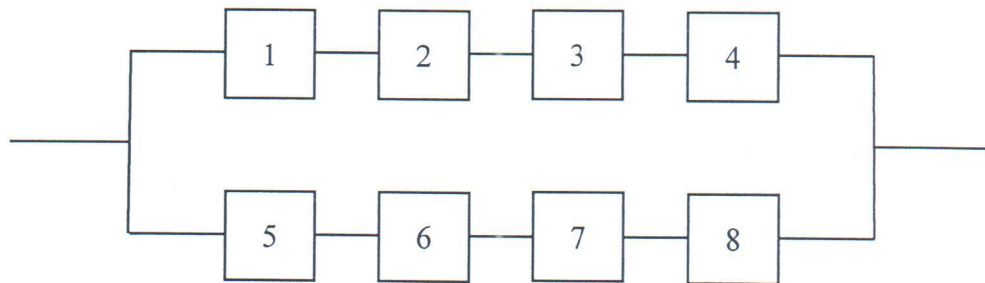


Figure Q.2.[d]

[6 marks]

2. [a] Takrifkan istilah-istilah yang berikut:

[i] Sistem

[2 markah]

[ii] Kebolehpercayaan

[2 markah]

[iii] Kelebihan

[2 markah]

[b] Apakah perbezaan di antara data ramalan dan data penilaian?

[3 markah]

[c] Satu sistem terdiri daripada 5 pam bebas dalam susunan bersiri di mana, setiap satunya mempunyai kebolehpercayaan 0.98.

[i] Kirakan kebolehpercayaan sistem tersebut.

[3 markah]

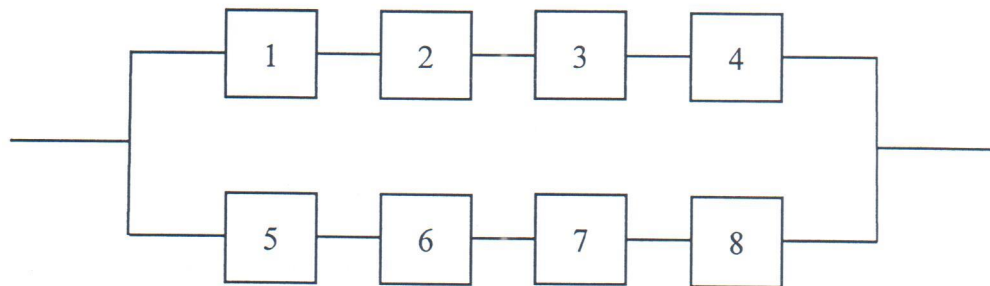
[ii] Hitungkan kebolehpercayaan sistem jika bilangan pam yang serupa ditambah menjadi 10 unit dalam siri.

[3 markah]

[iii] Hitungkan kebolehpercayaan setiap pam dalam sistem siri 10 unit jika kita hendak mengekalkan kebolehpercayaan sistem yang sama seperti di bahagian [i].

[4 markah]

[d] Terbitkan satu ungkapan umum untuk kebolehpercayaan model yang ditunjukkan dalam Rajah S.2[d] dan seterusnya hitungkan kebolehpercayaan sistem jika semua komponen mempunyai kebolehpercayaan 0.9.



Rajah S.2.[d]

[6 markah]

3. Hundred tonnes of liquid chlorine are transferred from the supply tank to the rail tank. The supply tank is mounted on weigh scales and liquid chlorine is transferred to the rail car using pressurized nitrogen. Liquid fill and vapor return lines are connected to the rail car with short sections of braided stainless steel hose with threaded connections. Two remote actuated emergency shutoff valves are available. The chlorine supply tank and plant nitrogen systems are protected from back flow by check valves. Table Q.3 shows the possible incidents based on the HAZOP study.

Data:

Wind velocity = 4.0 m/s
 Molecular weight = 71 kg/kg.mol
 Ambient Temperature = 291°K
 Ambient pressure = 1 atm

Table Q.3

Incident No	Incident description	Emitted release rate	Chlorine LC ₅₀ (ppm)	Estimated frequency (yr ⁻¹)
1	Small liquid leakage (equivalent to 12.7 mm hole). Duration = 10 min (estimated)	3.0	433	5.5 × 10 ⁻⁴
2	Small vapor leakage (equivalent to 12.7 mm hole). Duration = 10 min (estimated)	0.29	433	7.0 × 10 ⁻⁴
3	Large vapor leakage. Duration = 60 min (estimated)	2.4	177	3.6 × 10 ⁻⁶

3. Ratusan ton klorin cecair dipindahkan dari tangki bekalan ke tangki kereta api. Tangki bekalan dipasang pada berat skala dan klorin cecair dipindahkan ke kereta rel menggunakan nitrogen bertekanan. Paip-paip pengisian cecair dan pulangan wap dihubungkan dengan menggunakan seksyen pendek hos keluli tahan karat dengan sambungan bebenang. Terdapat dua injap pematian kecemasan gerak jauh. Sistem tangki bekalan klorin dan nitrogen dilindungi daripada aliran balik oleh injap sehalu. Jadual S.3 menunjukkan insiden yang mungkin berlaku berdasarkan kajian HAZOP yang telah dijalankan.

Data:

Halaju angin = 4.0 m/s
 Berat molekul = 71 kg/kg.mol
 Suhu persekitaran = 291°K
 Tekanan persekitaran = 1 atm

Jadual S.3

No Insiden	Keterangan Insiden	Kadar pembebasan (kg/s)	Klorin LC ₅₀ (ppm)	Anggaran Kekerapan (tahun ⁻¹)
1	Kebocoran cecair yang kecil (bersamaan 12.7 mm lubang). Masa = 10 min (jangkaan)	3.0	433	5.5×10^{-4}
2	Kebocoran wap yang kecil (bersamaan 12.7 mm lubang). Masa = 10 min (jangkaan)	0.29	433	7.0×10^{-4}
3	Kebocoran wap yang besar Masa = 60 min (jangkaan)	2.4	177	3.6×10^{-6}

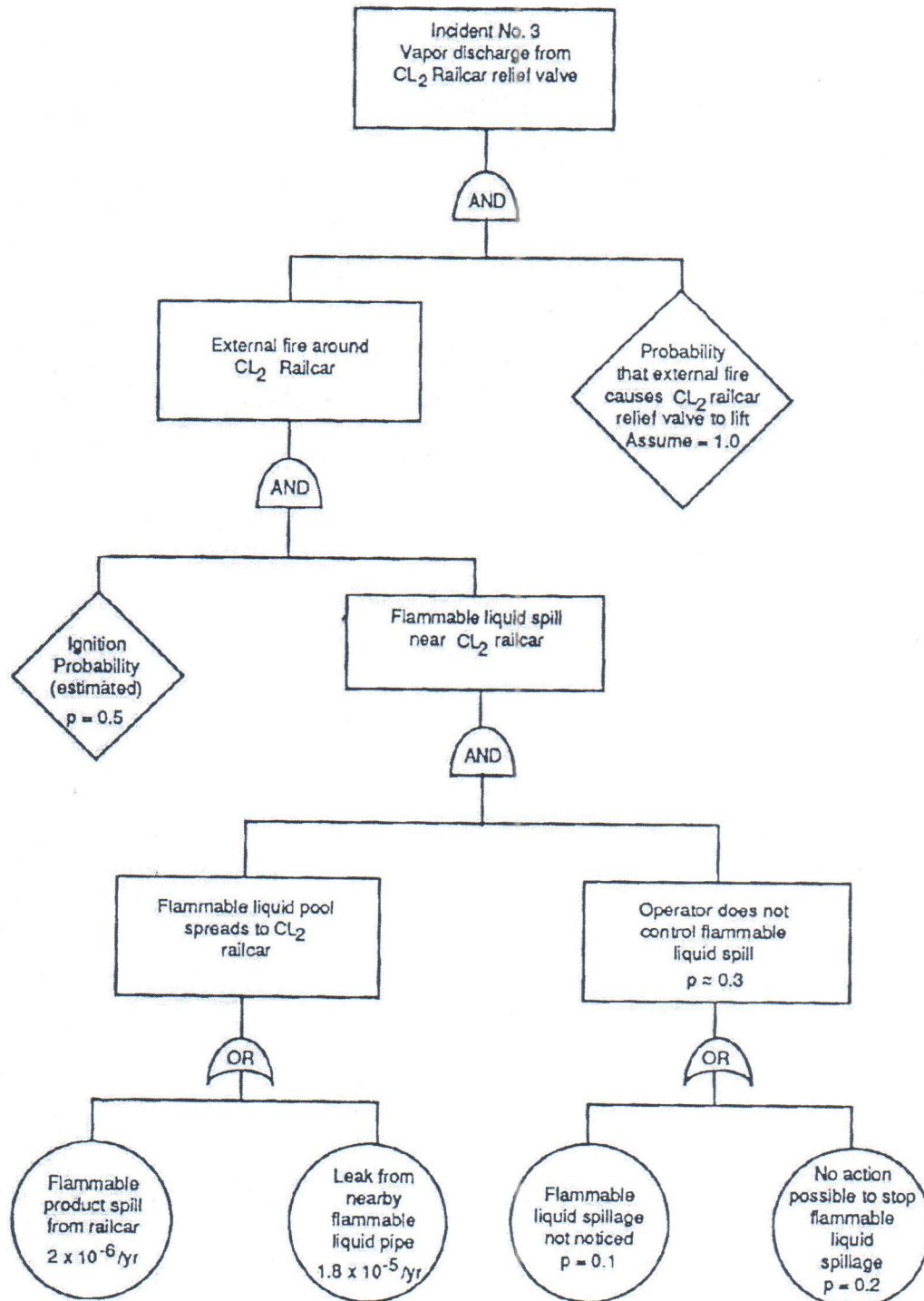


Figure Q.3

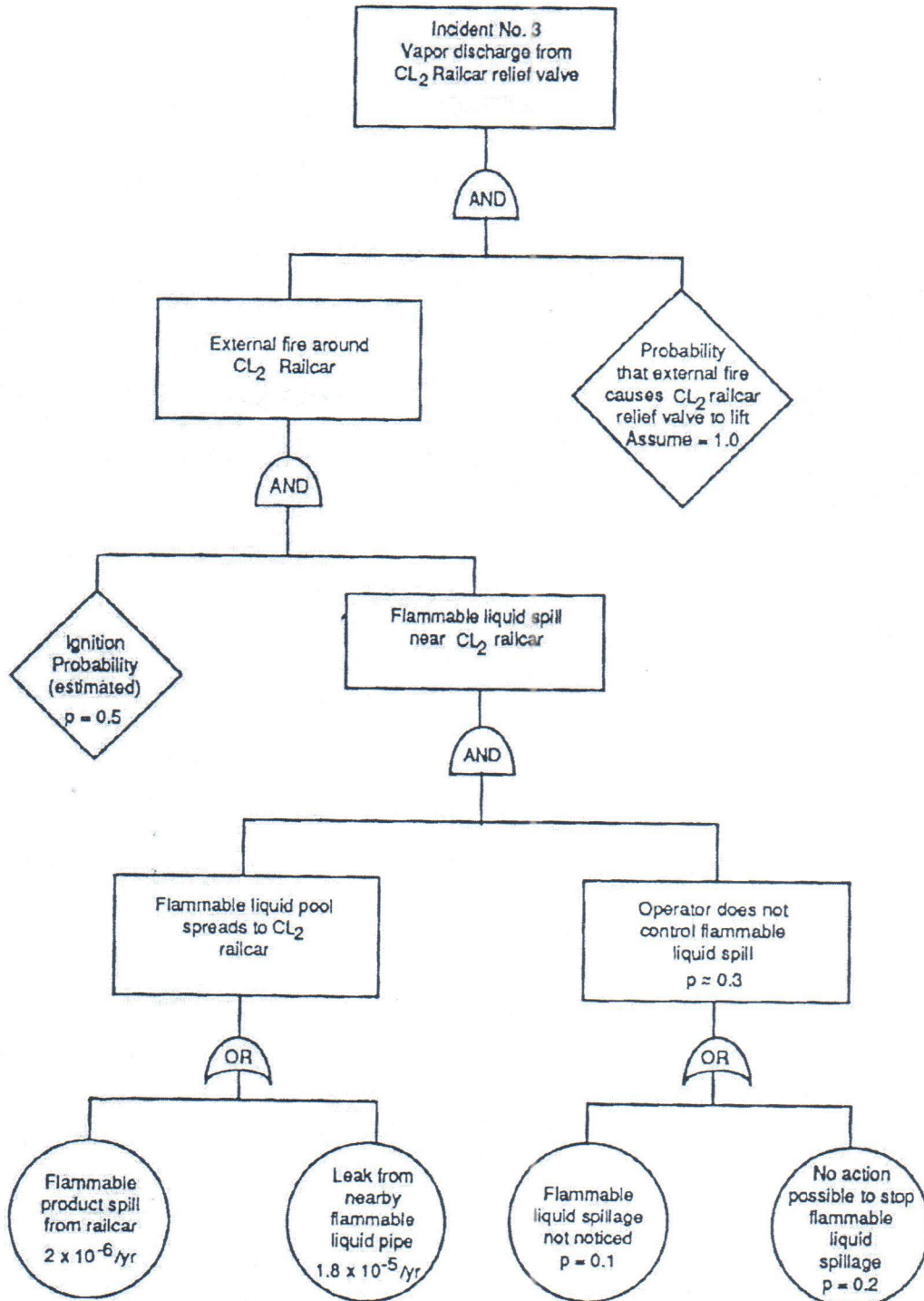
- [a] Determine the frequency of the top event for the Fault Tree Diagram in Figure Q.3 using the Minimum Cut Set method and compare the value for the Incident 3.

[5 marks]

- [b] Draw the individual risk contours for the three incidents away from the chlorine loading facility by assuming that 100 % fatality at LC50.

[20 marks]

...9/-



Rajah S.3

[a] Tentukan kekerapan peristiwa atas bagi Gambarajah Pokok Kegagalan dalam Rajah S.3 menggunakan kaedah Minimum Cut Set dan bandingkan nilai untuk Insiden 3. [5 markah]

[b] Lakarkan kontur risiko individu untuk tiga insiden tersebut bermula dari kemudahan fasiliti muat turun klorin dengan menganggap bahawa 100 % kematian pada LC50. [20 markah]

4. [a] Define the term relief containment in chemical industry? *[2 marks]*
- [b] Outline 2 types of relief containment techniques that are used in the industries. *[8 marks]*
- [c] Size a knockout drum to handle a relief stream with the following characteristics.

Peak vapor flow rate	7.5 kg/s
Total liquid volume in reactor	3 m ³
Liquid density	1000 kg/m ³
Vapor density	1 kg/m ³

Assume for the first case that the liquid does not foam. Repeat the exercise for a foaming liquid.

[15 marks]

4. [a] *Apa yang anda faham dengan istilah pembendungan pelepasan dalam industri kimia ?*

[2 markah]

[b] *Bincangkan 2 jenis teknik pembendungan pelepasan yang digunakan dalam industri.*

[8 markah]

[c] *Saizkan drum "knockout" untuk mengendalikan aliran lega dengan ciri-ciri berikut*

<i>Kadar aliran wap puncak</i>	<i>7.5 kg/s</i>
<i>Jumlah isipadu cecair dalam reaktor</i>	<i>3 m³</i>
<i>Ketumpatan cecair</i>	<i>1000 kg/m³</i>
<i>Ketumpatan wap</i>	<i>1 kg/m³</i>

Andaikan untuk kes pertama cecair tidak berbuih. Ulangi pengiraan untuk cecair berbuih.

[15 markah]

Appendix

Equations related to reliability

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

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

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

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

$$R_s = \prod_{i=1}^m R_i$$

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

$$R_p = 1 - F_p$$

$$= 1 - \prod_{i=1}^m F_i$$

$$= 1 - (1 - R_1)(1 - R_2) \dots (1 - R_m)$$

$$R_s = R_1 \times R_2 \times R_3 \times \dots \times R_m$$

$$R_s = 1 - m(1 - R)$$

$$R_p = 1 - (1 - R)^m$$

$$R_{sp} = [1 - (1 - R)^k]^m$$

$$R_{ps} = 1 - (1 - R^k)^m$$

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

where

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

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

Useful Equations

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

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

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

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/ft², X_f = ft, Q_m lb/hr

Probit Analysis:

Thermal Radiation

$$Y = -14.9 + 2.56 \ln \left(\frac{20 I^{\frac{4}{3}}}{10^4} \right)$$

I is Thermal radiation (W/m²)

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

Pool Fires:

$$\dot{y}_{\max} = 1.27 \times 10^{-6} \frac{\Delta H_c}{\Delta H^*}$$

$$\Delta H^* = \Delta H_v + \int_{T_a}^{T_{BP}} C_p dT$$

$$m_B = 1 \times 10^{-3} \frac{\Delta H_c}{\Delta H^*}$$

$$D_{\max} = 2 \sqrt{\frac{\dot{V}_L}{\pi \dot{y}}}$$

$$\frac{H}{D} = 42 \left(\frac{m_B}{\rho_a \sqrt{gD}} \right)^{0.61}$$

$$E_{av} = E_m e^{-SD} + E_s (1 - e^{-SD})$$

$$F_p = \frac{1}{4\pi x^2}$$

$$\tau_a = 2.02 (P_w X_s)^{-0.09}$$

$$P_{w(atm)} = \frac{RH}{100} \exp \left[14.4114 - \frac{5328}{T_{a(K)}} \right]$$

$$E_r = \tau_a Q_r F_p = \tau_a \eta m_B \Delta H_c A F_p$$

Jet Fires:

$$\frac{L}{d_j} = \frac{5.3}{C_T} \sqrt{\frac{T_f/T_j \left[C_T + (1 - C_T) \frac{M_a}{M_f} \right]}{\alpha_T}}$$

$$E_r = \tau_a Q_r F_p = \tau_a \eta m \Delta H_c F_p$$

TNT Model

$$W = \frac{\eta M E_c}{E_{TNT}}$$

$$Z_e = \frac{R}{(M_{TNT})^{1/3}}$$

$$P_s = \frac{P_o}{P_a}$$

TNO Model

$$\bar{R} = \frac{R}{(E/P_o)^{1/3}}$$

$$P_s = \Delta \bar{P}_s \cdot P_o$$

$$t_+ = t_+ \left[\frac{(E/P_o)^{1/3}}{c_o} \right]$$

Relief Containment

$$U_a = 0.083 \sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$

$$D_d = \sqrt{\frac{8Q_v}{\pi U_a}}$$

$$L_d = \frac{2V_L}{0.785 D_d^2}$$

$$L_d = \frac{3V_L}{0.785 D_d^2}$$

Table Transformation from Percentages to Probits¹

%	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

¹D. 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^{-3}
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^oR
- 10.731 psia ft³/lb-mol^oR
- 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^oR
- 0.7302 ft³ atm/lb-mol^oR
- 1.545.3 ft lb_f/lb-mol^oR

Gravitational Constant, g_c

- 32.174 ft-lb_m/lb_fs²
- 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^{-7} kg/m s = 2.4191 lb/ft-hr = 6.7197×10^{-6} lb/ft s