UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**CEB3023/CFB2073 - PROCESS SAFETY AND LOSS PREVENTION**
DATE	**:**	**21 APRIL 2025 (MONDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **TEN (10)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. Hydrogen cyanide (HCN) is a highly toxic chemical that can cause severe acute and chronic health effects in humans. Discuss the primary routes by which humans are exposed to HCN and the routes by which HCN could be eliminated from the body.

[10 marks]

b. A risk assessment study is conducted on a scenario where 500 residents in a densely populated urban area are exposed to chlorine vapors due to a pipeline rupture near a chemical plant. Estimate the number of deaths if the residents are exposed to the concentrations in **TABLE Q1**. Comment on the findings and discuss potential mitigation measures to reduce fatalities in future incidents.

TABLE Q1: Concentrations of chlorine at Different Exposure Time.

Concentration of chlorine (ppm)	Exposure Time (min)
50	30
125	15
250	10
300	5

[15 marks]

2. A worker in a wastewater treatment plant located in a rural area found a hole in a tank containing chlorine gas. This has caused 20 kg/s of chlorine gas to be released 50 m off the ground.

a. Estimate the concentration of the release 500 m downwind on the ground. Assume that the release occurs in the daytime during strong sunlight with a wind speed of 5.5 m/s.

[15 marks]

b. Discuss **THREE (3)** factors that could influence the dispersion of chlorine gas in the atmosphere and explain how they might affect the concentration of chlorine at ground level.

[10 marks]

3. a. Vapor cloud explosion (VCE) and boiling liquid expanding vapor explosion (BLEVE) are the dangerous explosions in the chemical process industries. Discuss the mechanisms of VCE and BLEVE.

[8 marks]

b. A large cloud of propane is released and eventually ignited resulted in a vapor cloud explosion. The blast causes partial demolition of houses located 500 m away from the source of the ignition.

i. Based on the following data, estimate the quantity of propane released that lead to the explosion.

ΔH_C of propane = 2043.1 kJ/mol
Equivalent energy of TNT = 4686 kJ/kg TNT
Molecular weight of propane = 44 g/mol
Explosion efficiency = 5 %

[8 marks]

ii. Estimate the injuries to people at the same distance and discuss **THREE (3)** methods to prevent the loss from the explosion.

[9 marks]

4. **FIGURE Q4** shows a vaporizer which supplies chlorine gas to a reactor. The vaporizer is heated by condensing steam. The designer's intention is that steam should be supplied at a certain pressure and flow rate to ensure the vaporization of chlorine matches the required demand. Construct a HAZOP study on the designer's intention by focusing on the process parameters of **FLOW** and **PRESSURE** using **THREE (3)** different guidewords, respectively. Suggest **THREE (3)** possible causes, consequences, and actions for each guideword.

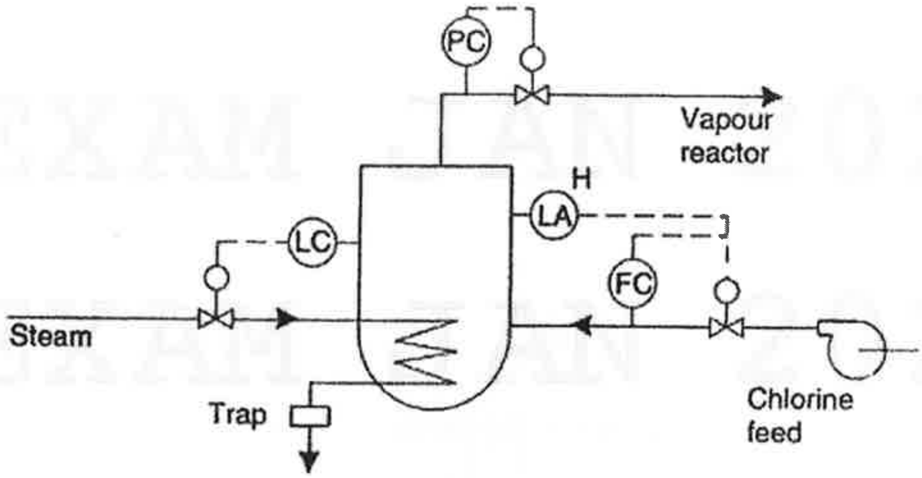

FIGURE Q4: Chlorine Vaporizer Instrumentation.

[25 marks]

-END OF PAPER-

APPENDIX

Data

e = Euler's number (2.718)

TNT Equivalency

$$z_e = \frac{r}{m_{TNT}^{1/3}}$$

$$m_{TNT} = \frac{\eta m \Delta H_c}{E_{TNT}}$$

Pasquill-Gifford dispersion model (Plume)

Ground Centreline Concentration

$$\langle C \rangle (x, 0{,}0) = \frac{Q_m}{\pi \sigma_y \sigma_z u} exp\left[-\frac{1}{2}\left(\frac{H_r}{\sigma_z}\right)^2\right]$$

Ground Centreline Concentration, release height, $H_r = 0$

$$\langle C \rangle (x, 0{,}0) = \frac{Q_m}{\pi \sigma_y \sigma_z u}$$

Maximum Concentration on Ground, for release above ground

$$(\sigma_z)_{x,max} = \frac{H_r}{\sqrt{2}}$$

$$\langle C \rangle_{max} = \frac{2Q_m}{e\pi u {H_r}^2}\left(\frac{\sigma_z}{\sigma_y}\right)$$

TABLE A-1: Damage estimates for common structures based on overpressure.

Pressure		
psig	**kPa**	**Damage**
0.02	0.14	Annoying noise (137 dB if of low frequency, 10–15 Hz)
0.03	0.21	Occasional breaking of large glass windows already under strain
0.04	0.28	Loud noise (143 dB), sonic boom, glass failure
0.1	0.69	Breakage of small windows under strain
0.15	1.03	Typical pressure for glass breakage
0.3	2.07	"Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% window glass broken
0.4	2.76	Limited minor structural damage
0.5–1.0	3.4–6.9	Large and small windows usually shatter; occasional damage to window frames
0.7	4.8	Minor damage to house structures
1.0	6.9	Partial demolition of houses, made uninhabitable
1–2	6.9–13.8	Corrugated asbestos shatters; corrugated steel or aluminum panels, fastenings fail, followed by buckling; wood panels (standard housing), fastenings fail, panels blow in
1.3	9.0	Steel frame of clad building slightly distorted
2	13.8	Partial collapse of walls and roofs of houses
2–3	13.8–20.7	Concrete or cinder block walls, not reinforced, shatter
2.3	15.8	Lower limit of serious structural damage
2.5	17.2	50% destruction of brickwork of houses
3	20.7	Heavy machines (3000 lb) in industrial buildings suffer little damage; steel frame buildings distort and pull away from foundations
3–4	20.7–27.6	Frameless, self-framing steel panel buildings demolished; rupture of oil storage tanks
4	27.6	Cladding of light industrial buildings ruptures
5	34.5	Wooden utility poles snap; tall hydraulic presses (40,000 lb) in buildings slightly damaged
5–7	34.5–48.2	Nearly complete destruction of houses
7	48.2	Loaded train wagons overturned
7–8	48.2–55.1	Brick panels, 8–12 in thick, not reinforced, fail by shearing or flexure
9	62.0	Loaded train boxcars completely demolished
10	68.9	Probable total destruction of buildings; heavy machine tools (7000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive
300	2068	Limit of crater lip

[1] V. J. Clancey, "Diagnostic Features of Explosion Damage," paper presented at the *Sixth International Meeting of Forensic Sciences* (Edinburgh, 1972).

TABLE A-2: Probit correlations for a variety of exposures.

Type of injury or damage	Causative variable	Probit parameters k_1	k_2
Fire[1]			
Burn deaths from flash fire	$t_e I_e^{4/3}/10^4$	−14.9	2.56
Burn deaths from pool burning	$t I^{4/3}/10^4$	−14.9	2.56
Explosion[1]			
Deaths from lung hemorrhage	p^o	−77.1	6.91
Eardrum ruptures	p^o	−15.6	1.93
Deaths from impact	J	−46.1	4.82
Injuries from impact	J	−39.1	4.45
Injuries from flying fragments	J	−27.1	4.26
Structural damage	p^o	−23.8	2.92
Glass breakage	p^o	−18.1	2.79
Toxic release[2]			
Ammonia deaths	$\Sigma C^{2.0}T$	−35.9	1.85
Carbon monoxide deaths	$\Sigma C^{1.0}T$	−37.98	3.7
Chlorine deaths	$\Sigma C^{2.0}T$	−8.29	0.92
Ethylene oxide deaths[3]	$\Sigma C^{1.0}T$	−6.19	1.0
Hydrogen chloride deaths	$\Sigma C^{1.0}T$	−16.85	2.0
Nitrogen dioxide deaths	$\Sigma C^{2.0}T$	−13.79	1.4
Phosgene deaths	$\Sigma C^{1.0}T$	−19.27	3.69
Propylene oxide deaths	$\Sigma C^{2.0}T$	−7.42	0.51
Sulfur dioxide deaths	$\Sigma C^{1.0}T$	−15.67	1.0
Toluene	$\Sigma C^{2.5}T$	−6.79	0.41

t_e = effective time duration (s)
I_e = effective radiation intensity (W/m^2)
t = time duration of pool burning (s)
I = radiation intensity from pool burning (W/m^2)
p^o = peak overpressure (N/m^2)
J = impulse (N s/m^2)
C = concentration (ppm)
T = time interval (min)

[1]Selected from Frank P. Lees, *Loss Prevention in the Process Industries* (London: Butterworths, 1986), p. 208.
[2]CCPS, *Guidelines for Consequence Analysis of Chemical Releases* (New York: American Institute of Chemical Engineers, 1999), p. 254.
[3]Richard W. Purgh, "Quantitative Evaluation of Inhalation Toxicity Hazards," in *Proceedings of the 29th Loss Prevention Symposium* (American Institute of Chemical Engineers, July 31, 1995).

TABLE A-3: Transformation from percentages to probits.

%	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.

TABLE A-4: Atmospheric stability classes for use with the Pasquill-Gifford dispersion model

Wind speed (m/s)	Day radiation intensity			Night cloud cover	
	Strong	Medium	Slight	Cloudy	Calm & clear
< 2	A	A – B	B	F	F
2 – 3	A – B	B	C	E	E
3 – 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
> 6	C	D	C	D	D

A : Extremely unstable
B : Moderately unstable
C : Slightly unstable
D : Neutrally stable
E : Slightly stable
F : Moderately stable

TABLE A-5: Equations for Pasquill-Gifford Dispersion Coefficients for Plume Dispersion

Pasquill-Gifford stability class	σ_y (m)	σ_z (m)
Rural conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A–B	$0.32x(1 + 0.0004x)^{-1/2}$	$0.24x(1 + 0.001x)^{+1/2}$
C	$0.22x(1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1 + 0.0004x)^{-1/2}$	$0.14x(1 + 0.0003x)^{-1/2}$
E–F	$0.11x(1 + 0.0004x)^{-1/2}$	$0.08x(1 + 0.0015x)^{-1/2}$

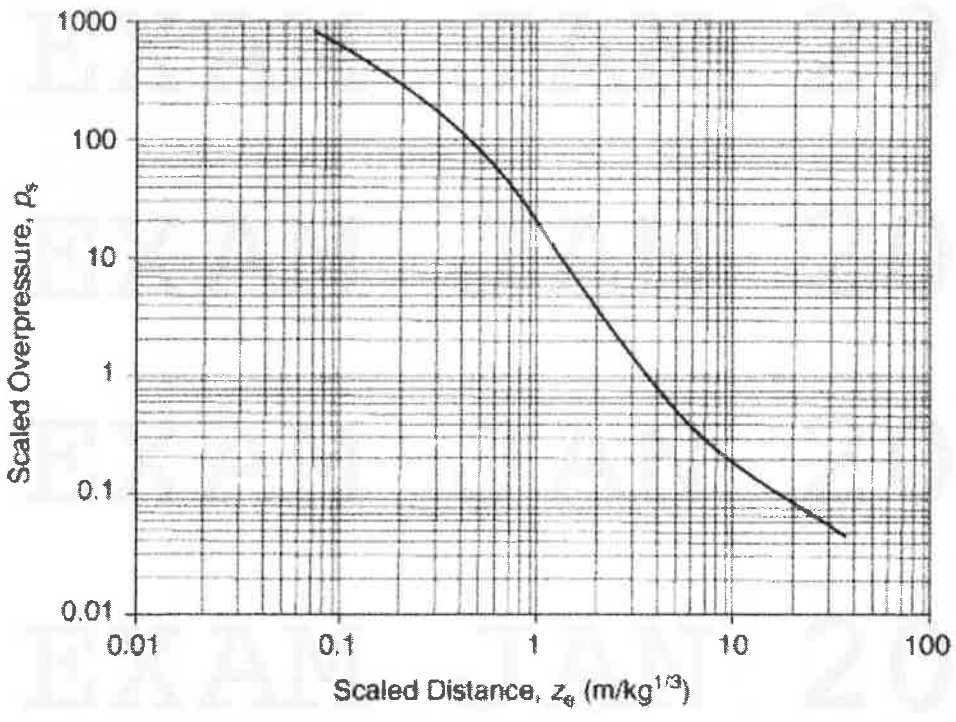

Figure A-1 Correlation between scaled distance and explosion peak side-on overpressure for a TNT explosion occurring on a flat surface. Source: G. F. Kinney and K. J. Graham, *Explosive Shocks in Air* (Berlin: Springer-Verlag, 1985).