UNIVERSITI
TEKNOLOGI
PETRONAS

# FINAL EXAMINATION
# MAY 2024 SEMESTER

**COURSE** : **CEB3023 - PROCESS SAFETY AND LOSS PREVENTION**
**DATE** : **7 AUGUST 2024 (WEDNESDAY)**
**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 **EIGHT (8)** pages in this Question Booklet including the cover page and appendix.
ii. **DOUBLE-SIDED** Question Booklet.

1. a. Process safety and occupational safety are both crucial in maintaining a safe work environment for all employees. While both are important in creating a safe work environment, they focus on different areas. Compare between process safety and occupational safety. Justify your answer with an appropriate example and suitable diagram. Based on your opinion, indicate which is more critical in a workplace.

[10 marks]

b. On June 1, 1974, the Nypro (UK) site at Flixborough experienced a catastrophic explosion, resulting in the deaths of 28 workers and injuries to 36 others. Evaluate the 'Anatomy of Incident' for this disaster and discuss the lessons learned from this tragic event.

[16 marks]

2. a. A risk assessment study is conducted on a scenario involving 500 workers being exposed to ammonia vapors due to a tank rupture in an ammonia production plant. Estimate the number of deaths if the workers are exposed to the concentrations in **TABLE Q2**. Compare the number of deaths if the concentration doubled at the similar exposure time. Comments on the finding.

**TABLE Q2**: Concentrations of Ammonia at Different Exposure Time.

| Concentration of ammonia (ppm) | Exposure Time (min) |
|---|---|
| 4500 | 60 |
| 2500 | 120 |
| 1500 | 180 |
| 150 | 240 |

[16 marks]

b. A 3-m diameter and 6-m high cylindrical storage tank is used to store water at atmospheric pressure. During inspection, a 3-cm hole develops 2 m from the bottom of the tank due to the careless driving of a forklift truck and at the current time, the liquid height is within 1 m of the top of the tank. With the aid of suitable sketch, estimate the amount of water spilled, assuming the worst-case scenario.

[8 marks]

3. a. The storage tank system shown in **FIGURE Q3** is used to store process feedstock. Overfilling of storage tanks is a common problem in the process industries. To prevent overfilling, the storage tank is equipped with a high-level alarm and a high-level shutdown system. The high-level shutdown system is connected to a solenoid valve that stops the flow of input stock.

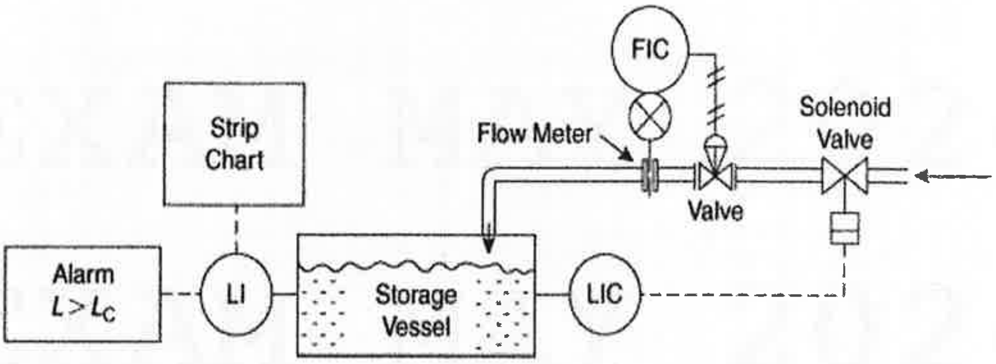

**FIGURE Q3**: Level control system with alarm.

Develop an event tree for this system using the "**failure of level indicator**" as the initiating event. Given that the level indicator fails 4 times/yr, estimate the number of overflows expected per year. Use the data in **TABLE Q3**.

**TABLE Q3**: Instrument Failure Rate Data.

| System | Failures/demand |
|---|---|
| High-level alarm | 0.01 |
| Operator stops flow | 0.10 |
| High-level switch system | 0.01 |

[16 marks]

b. Fault Trees and Event Trees are both analytical tools used in risk assessment and safety engineering. Discuss the relationship between these tools.

[10 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. Suggest **THREE (3)** possible causes, consequences, and actions for each guideword.

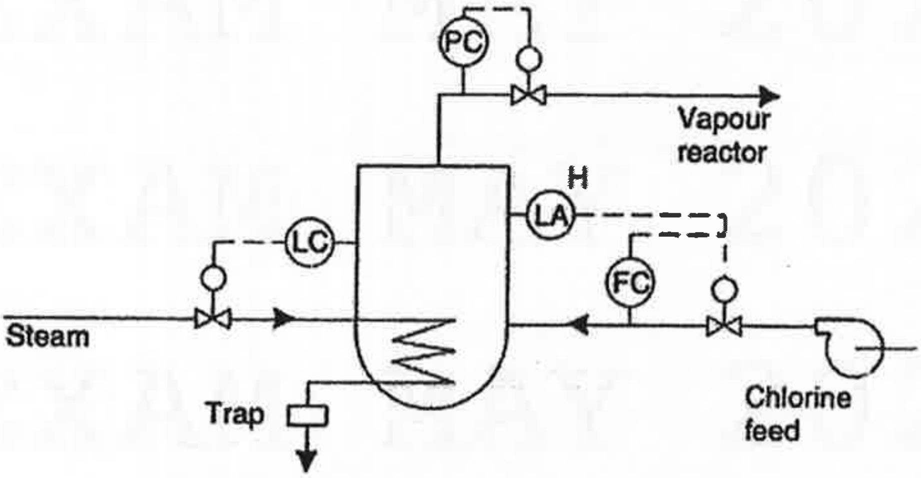

**FIGURE Q4**: Chlorine Vaporizer Instrumentation.

[24 marks]

-END OF PAPER-

## APPENDIX

**Data**

Gravitational constant, $g_c = 1\ (\text{kg.m/s}^2)/\text{N} = 32.174\ \text{ft-lb}_m/\text{lb}_f\text{-s}^2$

For water;

Density, $\rho = 1000\ \text{kg/m}^3 = 62.4\ \text{lb}_m/\text{ft}^3$

Temperature conversion

$^\circ R = {}^\circ F + 460$ $^\circ R = 1.8\ K$ $^\circ F = 1.8^\circ C + 32$

Conversion of concentration of vapours from mg.m$^{-3}$ to ppm;

$$C_{ppm} = \frac{22.4}{M}\left(\frac{T}{273}\right)\left(\frac{1}{P}\right)\left(C_{mg/m^3}\right)$$

where;

$M$ is the molecular weight in g/mol
$T$ is the temperature in Kelvin
$P$ is the pressure in atm

**TABLE A-1**: 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 | 4.25 | 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 |

**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 | $tI^{4/3}/10^4$ | −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).

**Flow of liquid through a hole**

Mass flow rate $Q_m$ resulting from a hole of area A

$$Q_m = AC_o\sqrt{2\,\rho g_c P_g}$$

**Flow of liquid through a hole in a tank**

The instantaneous mass flow rate $Q_m$ resulting from a hole of area $A$ is given by:

$$Q_m = \rho\, C_o A\sqrt{2\left(\frac{g_c\, P_g}{\rho} + g h_L^o\right)}$$

The liquid level height in the tank is given by;

$$h_L = h_L^o - C_o\left(\frac{A}{A_t}\right)\sqrt{2\left(\frac{g_c P_g}{\rho} + g h_L^o\right)}\,t + \frac{g}{2}\left(C_o\frac{A}{A_t}t\right)^2$$

The time $t_e$ for the vessel to empty to the level of the leak is given by the equation below;

$$t_e = \frac{1}{C_o g}\left(\frac{A_t}{A}\right)\left[\sqrt{2\left(\frac{g_c P_g}{\rho} + g h_L^o\right)} - \sqrt{\frac{2 g_c P_g}{\rho}}\right]$$

where

| | |
|---|---|
| $\rho$ | is the density of material |
| $A$ | is the leak cross sectional area |
| $C_o$ | is the discharge coefficient |
| $g_c$ | is the gravitational constant |
| $g$ | is the acceleration due to gravity |
| $P_g$ | is the gauge pressure |
| $h^o{}_L$ | is the initial height of the liquid level |