UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**CBM5143/CCM5143 – SAFE DESIGN AND OPERATION**
DATE	**:**	**18 APRIL 2025 (FRIDAY)**
TIME	**:**	**9:00 AM – 12:00 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

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

Note :

i. There are **NINE (9)** printed pages in this **double-sided** Question Booklet including the cover page and appendices.

1. You are a process safety engineer at a petrochemical plant that operates a high-pressure hydrocarbon reactor. The reactor is prone to thermal runaway reactions, which could lead to overpressure and loss of containment. The plant currently has the following safeguards in place as described in **TABLE Q1**. The risk assessment indicates that the initiating event frequency of reactor overpressure is 1×10^{-1} per year. The company follows a risk tolerance threshold requiring the final risk to be LESS (<) than 1×10^{-5} per year.

TABLE Q1: Description of safeguards

Process Control System (PCS)	Monitors temperature and pressure but is not an independent protection layer (IPL).
High-Temperature Alarm	Triggers an operator response but requires manual intervention.
Pressure Relief Valve (PRV)	Automatically vents excess pressure if a critical threshold is reached
Emergency Shutdown System (ESD, SIL 2)	Shuts down the reactor when abnormal conditions are detected.
Operator Intervention	Plant operators are trained to respond to alarms and take corrective actions.

a. Analyze whether the current safeguards meet the criteria for Independent Protection Layers (IPLs) in Layer of Protection Analysis (LOPA) based on the LOPA principles. Provide justification for each safeguard. Using the given data, evaluate whether the existing IPLs sufficiently reduce the risk to an acceptable level.

[13 marks]

b. Develop a comprehensive LOPA strategy to mitigate the risk of reactor overpressure to an acceptable level with an appropriate number of IPLs. Present your findings in a risk matrix format that highlights the advantages of the new strategy compared to the old one. Justify your selection of IPLs based on quantitative risk assessment, operational feasibility, and regulatory compliance.

[13 marks]

2. During a routine inspection of the tank farm, a small leak was detected in one of the tanks storing gasoline. The leak was reported, but due to a delay in repair scheduling, it was not immediately fixed. Meanwhile, maintenance work involving welding was being conducted on a nearby pipeline approximately 20 meters from the leaking tank. The welding activity generated sparks, which ignited the flammable vapors escaping from the leaking tank. This led to a flash fire that quickly spread to the surrounding area. The fire caused significant damage to the storage tank and nearby equipment, resulting in operational downtime and financial losses. Fortunately, no injuries or fatalities occurred due to the prompt response of the plant's emergency team.

   a. Identify and explain the three essential elements of the fire triangle present in this incident. Describe the difference between active and passive fire protection systems and provide **ONE (1)** example of each relevant to this scenario.

   [7 marks]

   b. Perform a basic risk assessment by identifying the hazard, consequence, likelihood, and risk level for this incident. Based on this case, suggest **TWO (2)** key safety lessons that should be incorporated into plant safety procedures to prevent future incidents.

   [8 marks]

   c. Propose a comprehensive fire and explosion mitigation strategy that integrates **engineering, administrative, and procedural controls**. Justify how this strategy would provide long-term risk reduction.

   [9 marks]

3. A distillation process for crude methanol without a relieve device is shown in **FIGURE Q3**. As a process engineer, you have been asked to design and explain the requirement of relieve system to prevent overpressure scenarios. Propose and sketch **ALL** the suitable relieve locations on the process flow diagram. Describe the suitable type of relief devices that should be used at each location and provide recommendations for total containment for this system. Describe **FOUR (4)** examples of scenarios requiring a combination of spring-operated relieve in series with rupture disc.

Note: The **FIGURE Q3** sheet is to be included together with the answer booklet.

[26 marks]

4. "Thermal expansion" phenomenon is the tendency of matter to increase in length, area or volume, changing its size and density in response to an increase in temperature. This can lead to stress in pipes and equipment, potentially leading to leaks, fire and explosion. In a chemical plant, a cooler has been identified to possibly experience this phenomenon. As a safety engineer you are required to design pressure relieve valve to mitigate this possibility. **TABLE Q4** shows some design criteria for the relive sizing.

TABLE Q4: Design criteria for relieve sizing

Design Criteria	Value
Blocked-in area, ft^3	10000
Maximum temperature, °F	550
Minimum temperature, °F	70
Heat transfer coefficient, Btu/hr ft^2 °F	75

a. Determine the size of relieve required to protect the cooling coils filled with water as the liquid medium against thermal expansion. The tubes can withstand a pressure of 1000 psig and that the normal operating pressure is 200 psig.

[10 marks]

b. Estimate the size of relieve when alcohol is used as a liquid medium. Compare the size of relieve obtained with the answer in **part (a)** and provide reasons for the differences.

[14 marks]

– END OF PAPER –

APPENDIX I

Protection layer	Typical PFD
Pressure Relief Valve (PRV)	0.01
Secondary PRV (Redundant)	0.01
Flare System	0.1
Check Valve with High Reliability	0.1
Active Fire Protection System (Sprinklers, Water Deluge)	0.1 - 0.01
Operator Response to Alarm (Highly Trained, Regular Drills)	0.1
Operator Response to Alarm (Average Training, Some Delay Possible)	0.3
Operator Response with Manual Shutdown (Limited Training, Slow Response)	0.5
Secondary Containment (Bunds, Dikes, Drainage Systems)	0.1
Explosion Suppression System	0.01
SIL 1	0.1
SIL 2	0.01
SIL 3	0.001
SIL 4	0.0001

$$Mitigated\ risk = \frac{Initiating\ Event\ Frequency\ (IEF)}{RRF\ of\ IPL_1 \times RRF\ of\ IPL_2 \times \ldots . \times RRF\ of\ IPL_n}$$

$$Risk\ Reduction\ Factor, RRF = \frac{1}{PFD}$$

APPENDIX II

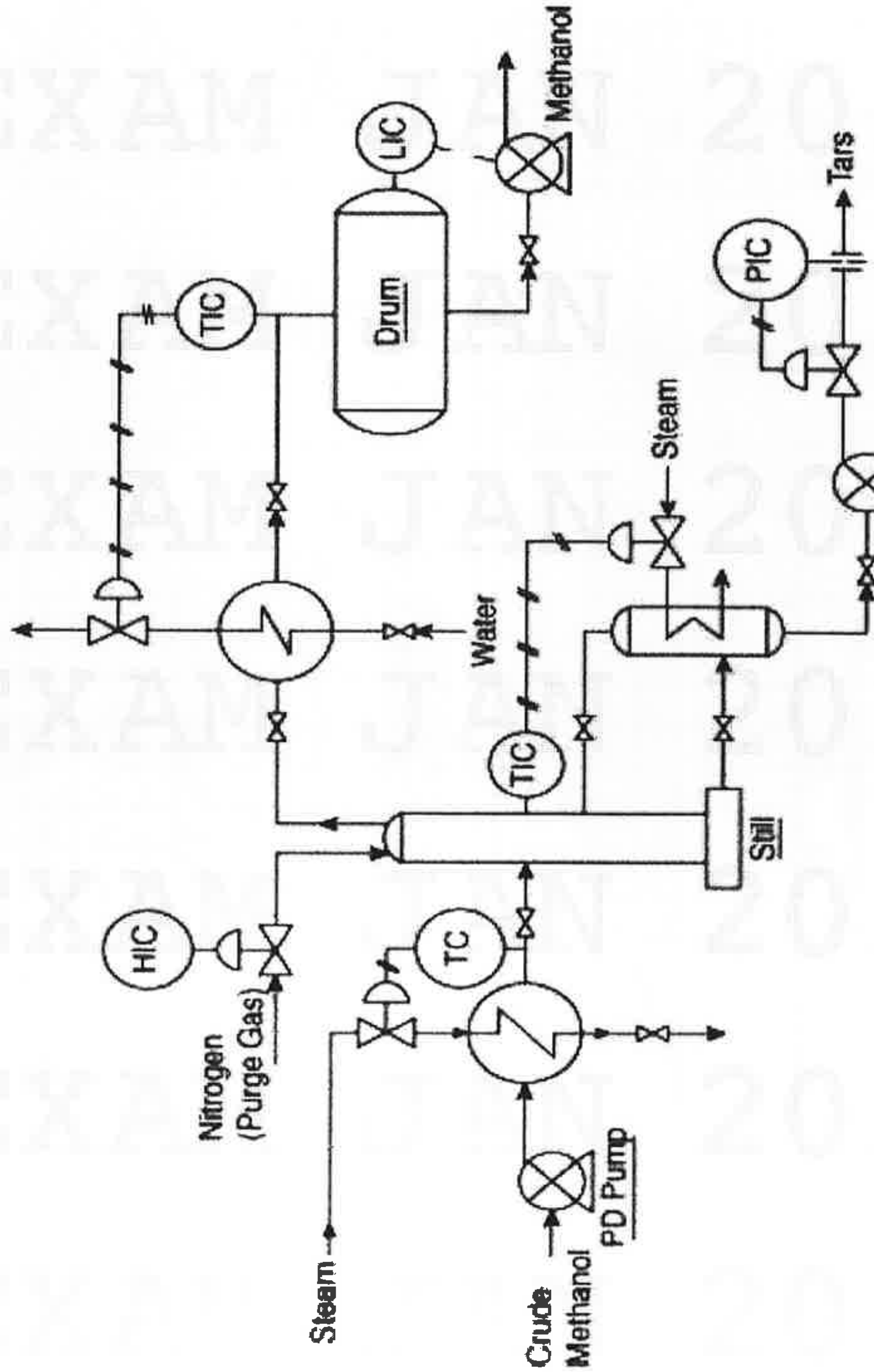


FIGURE Q3

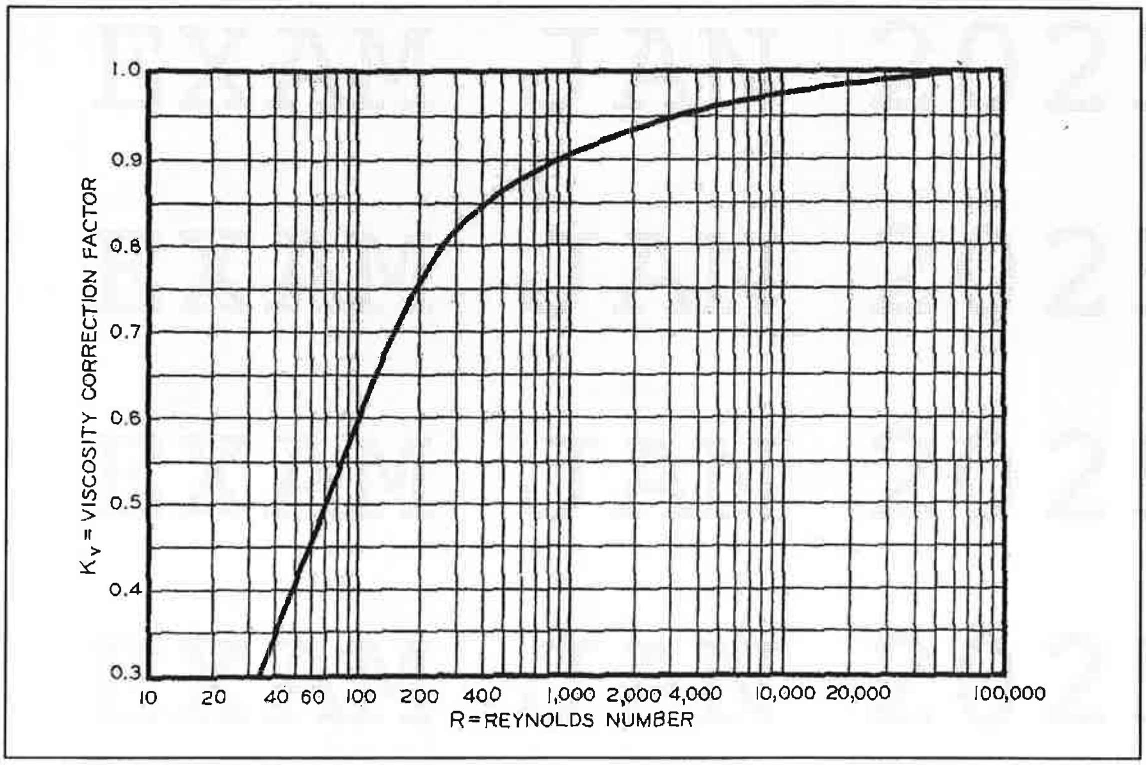
APPENDIX III

Conventional Spring-Operated Reliefs in Liquid Service

$$Q_V = \frac{\beta}{\rho C_p} U A(T - T_a)$$

$$A = \left[\frac{in^2\, psi^{1/2}}{38\, gpm} \right] \frac{Q_v}{C_o K_v K_p K_b} \sqrt{\frac{\rho / \rho_{ref}}{1.25 P_s - P_b}}$$

Viscosity Correction Factor



Overpressure Correction Factor