



UNIVERSITY OF  
KWAZULU-NATAL  
INYUVESI  
YAKWAZULU-NATALI

## SCHOOL OF ENGINEERING

### MAIN EXAMINATIONS: JUNE 2019

**COURSE AND CODE:** SAFETY AND LOSS PREVENTION

ENCH3SL

**DURATION:** 2 HOURS

**TOTAL MARKS:** 100

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**INTERNAL EXAMINER(S):** MR MG NTUNKA

**INTERNAL MODERATOR(S):** DR K MOODLEY

**EXTERNAL MODERATOR:** DR BE MVELASE

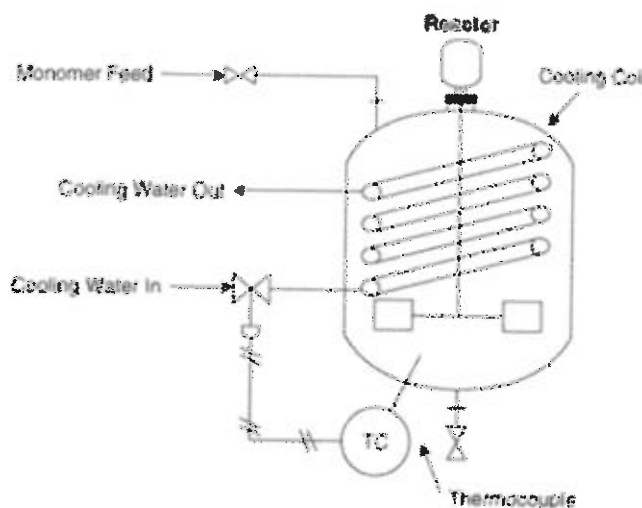
**INSTRUCTIONS:**

1. ALL questions should be attempted.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

**Student Number:**

**QUESTION 1**

A reactor system is shown in the Figure 1 to which the HAZOP procedure can be applied.



**Figure 1. An exothermic reaction controlled by cooling water**

This reaction is exothermic, and a cooling system is provided to remove the excess energy of reaction. If the cooling flow is interrupted, the reactor temperature increases, leading to an increase in the reaction rate and the heat generation rate. The result could be a runaway reaction with a subsequent increase in the vessel pressure possibly leading to a rupture of the vessel. The temperature within the reactor is measured and is used to control the cooling water flow rate by a control valve.

- Name the study nodes of the process system. (4)
- Using relevant guidewords, perform a HAZOP study on this unit to improve the safety of the process as shown in Figure 1. Use as study node the stirrer with process parameter: "Agitation".

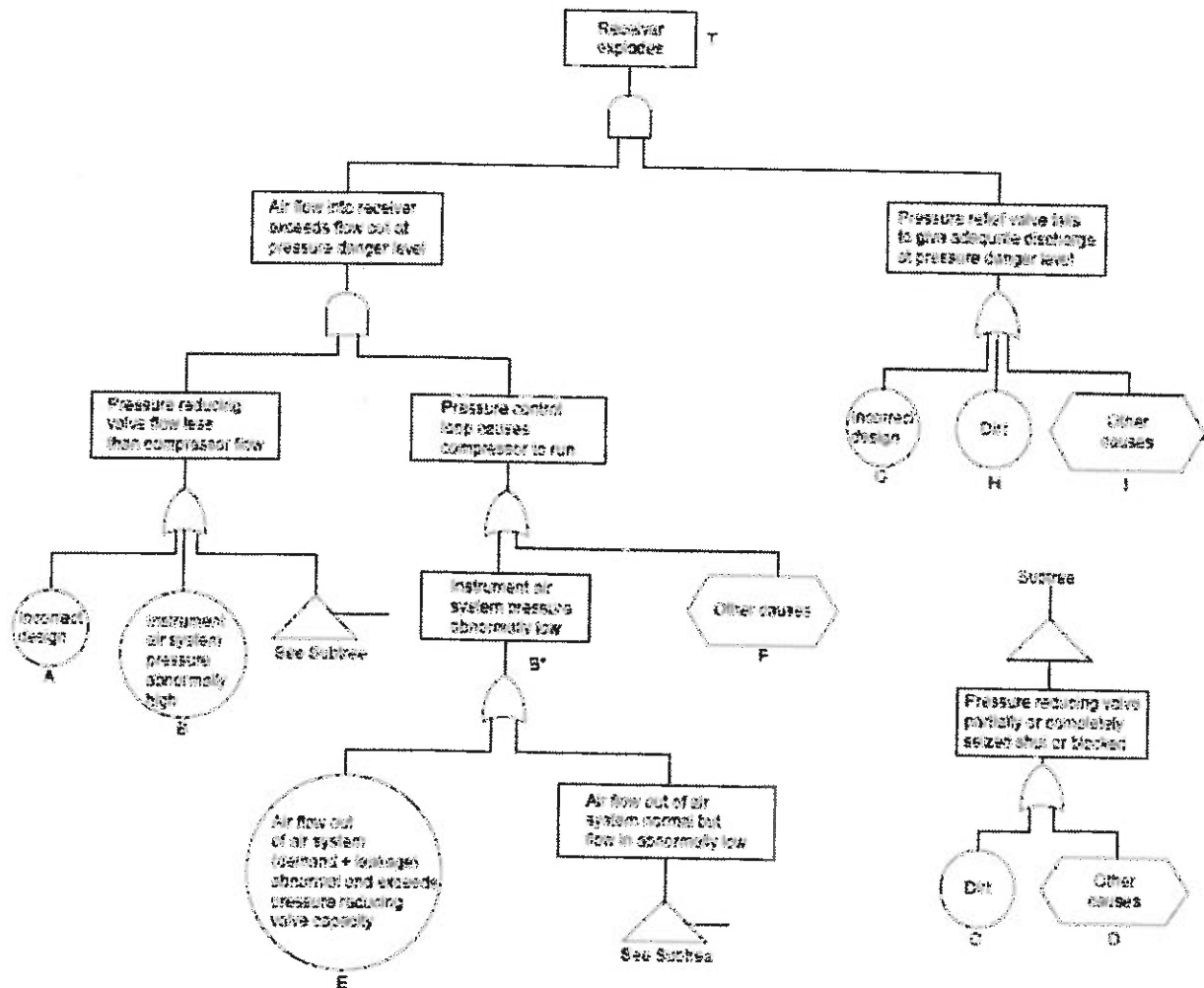
**Note:** Present your HAZOP results in tabular format with the design intention, study node, deviations, possible causes, possible consequences and actions required.

(11)

**TOTAL /15/**

**QUESTION 2**

Figure 2 shows the fault tree for the 'Receiver explosion' due to overpressure.



- a) Find the minimal cut sets for the top event 'Receiver explosion' due to overpressure.

(12)

- b) Draw the equivalent fault tree diagram expressed by the minimal cut sets.

(8)

TOTAL /20/

**QUESTION 3**

- a) The probit equation for carbon monoxide is:

$$Y = -37.98 + 3.7 \ln(Ct)$$

The gases from a factory boiler are heat exchanged with the incoming air in order to raise its temperature to about 25°C. At the exchanger there is leakage which is undetected for 30 minutes with the result that the 135 employees in the factory are breathing air contaminated with 0.25% (2500 p.p.m.) of carbon monoxide for that time. Estimate how many fatalities can be expected.

(3)

- b) Why must children especially be protected from environmental contaminants? Use the term lethal dose (LD) in your answer.

(2)

**TOTAL /5/****QUESTION 4**

- a) Describe with one example the three ingredients of any fire.

(3)

- b) List three common fire prevention / protection features for chemical plants.

(3)

- c) An informal industry rule is to design occupied control rooms to withstand a one tonne blast of TNT at 30.5 m. How far away (in m) from this one tonne blast must a residential home be in order to receive no more than minor damage to the house structures? This corresponds to an overpressure of 0.05 bar.

(3)

- d) Liquid methanol is stored in a vessel. Its vapor is inerted with nitrogen to a total pressure of 3.7 mm of mercury gauge pressure. Will it be flammable if the vapour escapes and mixes with air? Use the fire triangle diagram to make this determination.

**DATA:**  $P_{Methanol}^{sat} = 125.9 \text{ mm of mercury}$ ; LFL = 7.5%, UFL = 36% by volume,  
LOC = 10% oxygen

(11)

**TOTAL /20/**

**QUESTION 5****True or False Questions – (No Negative Marking)**

- a) Oxygenated hydrocarbons tend to be of lower reactivity than the parent hydrocarbon. (1)
- b) Methyl isocyanate was the substance involved in the 1984 Bhopal accident. (1)
- c) Reactions involving the nitration of hydrocarbons are significantly exothermic. (1)
- d) In operation of a heat exchanger, vibrations – either intrinsic or transmitted – during operation can cause structural damage. (1)
- e) Chlorine is more toxic than ammonia in the same molar quantity. (1)

**Short Answers**

- f) Give the 4 shortcomings in the application of hygienic standards for developing environmental protection standards. (4)
- g) What is the difference between self-heating and pyrophoric materials. (2)
- h) What can a car exhaust catalytic converter not do? (2)
- Convert  $NO$  to  $N_2$ .
  - Convert  $N_2O$  to  $N_2$ .
  - Oxidize  $CO$  to  $CO_2$ .
  - To convert all unburnt hydrocarbons to  $CO_2$  and  $H_2O$
  - Remove  $SO_2$  from the exhaust gas.
- i) What is the difference between self-heating and pyrophoric materials? (2)
- j) Can the method “Oxygen Balance” be applicable to hydroxylamine,  $NH_2OH$ ? If yes, what is the Oxygen Balance of that compound and what does it represent using the CHETAH oxygen balance criteria?

$$\text{Oxygen Balance} = -1600 \frac{\left(2x + \frac{y}{2} - z\right)}{M.W} \text{ wt\%}$$

M.W. of  $NH_2OH = 33.03 \text{ g/mol}$

(5)

**TOTAL /20/**

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**QUESTION 6**

- a) You are a successful project manager at Early Environmental Advice (EEA), a consulting firm with national accounts with several major manufacturers. You are assigned to manage environmental compliance audits at several plants of X Industries, Inc., a large company. The contract is being conducted under legal counsel and the results are to be handled in order to maintain confidentiality under the law. At one plant, you discover the release of a toxic chemical that you are certain threatens public health. You contact the X attorney, Paul, who ordered the study and report your findings. Paul directs you to stop work at that site, move on to another plant, and not submit your findings in writing. You point out the need to report this to the responsible agency, Paul reminds you of the contract, which provides for the confidentiality of the findings. You are told that his staff will handle any reporting and warned that this information and your conversations are to be kept confidential. "Do not discuss it with anyone! If I need any additional information, I will ask for it. Take your team and go on to the next plant on the list." Your attempts to learn how Paul plans to proceed on this information are met with, "It is not your concern. You do your job [i.e., investigate] and I will do mine. If I need any additional information, I will ask for it." Briefly discuss in steps how you will solve this ethical dilemma.

(6)

- b) The Bhopal plant (partially owned by Union Carbide and partially owned locally in India) produced pesticides, amongst others carboxyl. An intermediate chemical in this process is methyl isocyanate (MIC), which is extremely dangerous. It is reactive, toxic, volatile, and flammable. The TLV for MIC is 0.02 ppm.

The disaster started with the contamination of a large MIC storage tank with a large amount of water (how is still unclear), leading to an exothermic chemical reaction. Insufficient cooling of the storage tank led to a runaway reaction with an accompanying temperature increase past the boiling point of MIC (39°C). The MIC vapors traveled through a pressure relief system and into a scrubber and flare system installed to consume the MIC in case of a release. Unfortunately, the scrubbing and flare systems were not operating. An estimated 40 metric tons of MIC vapor was released, the toxic cloud spread to the adjacent town (vapors stayed close to the ground due to the density of about twice that of air), killing over 2500 civilians and injuring an estimated 200 000 more. The exact cause for the contamination of the MIC is not known. However, several design measures could have prevented this disaster:

- a well-executed safety review or HAZOP study would possibly have identified the problem;
- adequate refrigeration of the storage tank could have prevented the runaway reaction;
- the scrubber and flare system should have been fully operational to prevent the release;
- the inventory of MIC should have been minimized, for example, by redesigning the process to produce and consume MIC in a highly localized area (inventory <10kg); although storage of MIC was convenient, it was not necessary;
- an alternative reaction route, not involving MIC, could have been adopted.

**Name and associate** a strategy of inherently safer design to the design measures suggested to the Bhopal plant after that incident.

(10)

**QUESTION 6 continued ...**

- c) Phosgene ( $COCl_2$ ) is one of the most toxic chemicals known. It was used as mustard gas in World War I. Currently, phosgene is used as a raw material in the manufacture of pesticides and urethanes. It has been suggested that dimethyl carbonate (DMC,  $CH_3-O-(C=O)-O-CH_3$ ) can serve as a reactant in many of the same processes that use phosgene. However, the traditional method for manufacturing DMC is from phosgene and methanol.

**Phosgene manufacture:**  $CO + Cl_2 \rightarrow COCl_2$

**DMC manufacture:**  $COCl_2 + 2CH_3OH \rightarrow CH_3-O-(C=O)-O-CH_3 + 2HCl$

Give 2 principles for sustainability considerations in process design illustrated in this new process.

(4)

**TOTAL /20/**

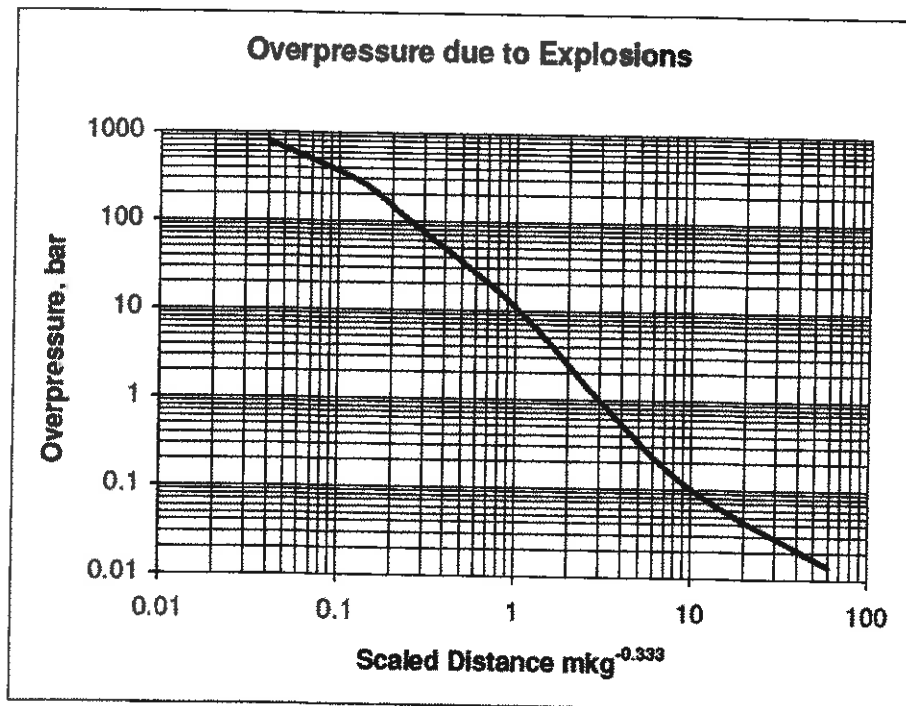
**DATA SHEET**

TNT: Heat of detonation,  $\Delta H_{TNT} = 4,652 \text{ MJ/kg}$

Efficiency factor  $\varepsilon = 1$

$$m_{TNT} = \frac{\varepsilon m_c \Delta H_c}{\Delta H_{TNT}}$$

$$\text{scaled distance} = \frac{\text{actual distance}}{m_{TNT}^{1/3}}$$



Transformation of percentages into 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 |

**DETACH THIS PAGE AND SUBMIT WITH YOUR ANSWER BOOK**

**STUDENT NUMBER:** \_\_\_\_\_

**EQUILATERAL TRIANGULAR DIAGRAM**

