UNIVERSITY OF
KWAZULU-NATAL

DISCIPLINE OF CHEMICAL ENGINEERING

EXAMINATIONS: JUNE 2023

COURSE AND CODE: **SAFETY & LOSS PREVENTION** **ENCH3SL**

DURATION: 2 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: Mr C A Baah

EXTERNAL EXAMINERS: Prof A T Kaniki

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.

QUESTION 1

A speciality company has developed a batch process to produce a new polymer. Reactants A and B combine to form the desired product. Each batch operates for three weeks, and 5 batches are operated per year.

The reaction involving A and B is nearly instantaneous and highly exothermic. Safe operation of this process requires that cooling water continuously be flowing through the jacket. Hazard analysis determined that loss of cooling water could cause a "runaway" reaction and physical explosion of the vessel. The plant's safety division performed a quantitative consequence analysis of the physical explosion of this vessel. The analysis determined that the explosion would result in the following consequence:

- Probable loss of life: 5.64 fatalities
- Probable Injuries: 13.24 injuries

The following layers of protection were identified as a safeguard against explosion of the vessel due to runaway reaction.

- A rupture disk set to relieve the pressure well below the design pressure of the vessel
- Operator intervention to high vessel temperature, high vessel pressure, and low cooling water flow alarms

A safety instrumented system that injects a reaction-inhibiting chemical if the vessel temperature or pressure exceeds predetermined conditions was recommended in the process hazards analysis.

A process engineer determined the following frequencies and failure probabilities after reviewing the history of the plant.

- Cooling water pump fails: 1/75/year
- Rupture disc fails: 0.0956
- Operator response to cooling water loss: 0.1

Perform ETA (Event Tree Analysis) and calculate the probability for explosion to take place.

The plant is either operational or not.

HINT: The plant is operational: 5 batches/year; 3 weeks/batch; There are 7 days per week and 24 hours/day.

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QUESTION 2

Determine the concentration of hydrogen sulphide in ppm that would be estimated to cause 10% fatalities if exposed for 15 minutes. (10)

What is the average concentration that would cause the same amount of fatalities for workers on an 8 hour shift? (2)

DATA:

The probit equation for H_2S is $Y = \ln (C^{1.9}t) - 11.15$, where C is in ppm and t in min.

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

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QUESTION 3

The top event for the FTA (Fault Tree Analysis) shown below is a Shell-tube heat exchanger failure. Use Table 1 and Table 2 to determine the top event probability if p(X1) is equal to 0.001. **Further information is provided on page 4.**

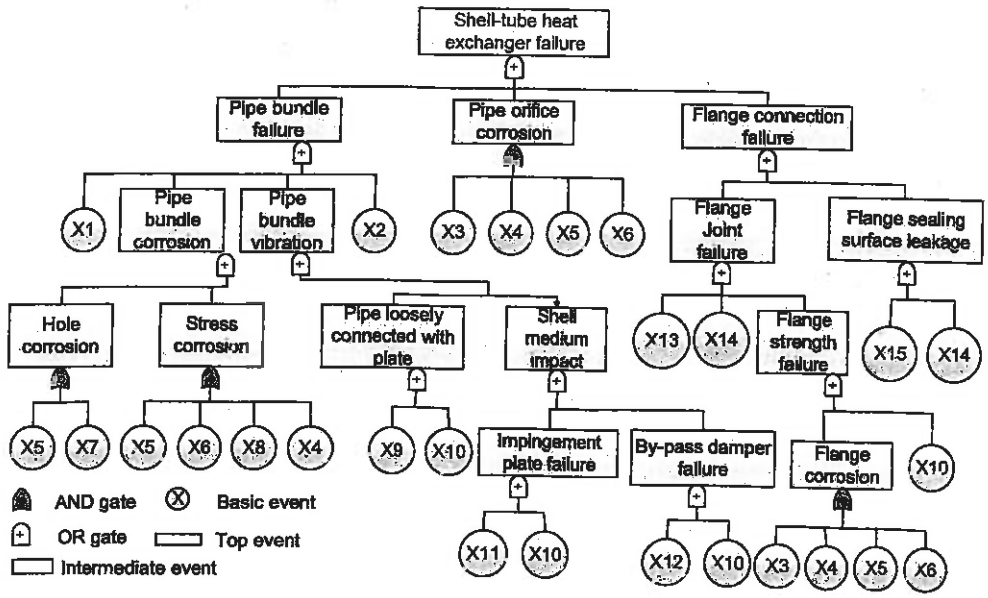


Table 1: Basic events of FTA.

Number	Name	Probability
X1	Fouling resistance	0.001
X2	Medium erosion	0.02
X3	Stress concentration	0.02
X4	Poor corrosion resistance of materials	0.02
X5	Medium	0.015
X6	Service conditions	0.02
X7	Material defect	0.015
X8	pulling stress	0.006
X9	Thermal stress	0.03
X10	Confection defect	0.025
X11	Without impingement	0.002
X12	Without by-pass damper	0.002
X13	Bolt corrosion	0.001
X14	Spacer failure	0.001
X15	Uneven flange face	0.002

Table 2: Intermediate events of FTA

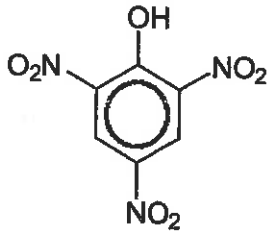
Number	Name
M1	Pipe bundle failure
M2	Pipe orifice corrosion
M3	Flange connection failure
M4	Pipe bundle corrosion
M5	Pipe bundle vibration
M6	Flange joint failure
M7	Flange sealing surface leakage
M8	Hole corrosion
M9	Stress corrosion
M10	Pipe loosely connected with plate
M11	Shell medium impact
M12	Flange strength failure
M13	Impingement plate failure
M14	By-pass damper failure
M15	Flange corrosion

QUESTION 4

Evaluate the chemical reaction hazard of picric acid by the following methods; and comment on your results:

a) Explosibility screening (presence of reactive groups)
b) Average Bond Energy Summation. Picric acid (see the formula below) decomposes to Carbon, Nitrogen, Water (vapour) and Carbon dioxide. Write down the decomposition reaction.

Picric acid:



Reactant	
Bond type	**Bond energy [kJ/mol]**
	355
Carbon bond in the ring	513
	413
	407
	331
	871

Products	
Bond type	**Energy [kJ/mol]**
N_2 (between nitrogen atoms)	946
H_2O (2 bonds between oxygen and two hydrogen atoms)	927 (per 2 bonds)
CO_2 (2 bonds between carbon and two oxygen atoms)	1608 (per 2 bonds)

c) Oxygen balance

Molecular weights: C: 12, H: 1, O: 16, N: 14

Oxygen balance:

$$C_xH_yO_z + \left(2x + \frac{y}{2} - z\right)O = xCO_2 + \frac{y}{2}H_2O$$

$$O.B. = -1600\frac{\left(2x + \frac{y}{2} - z\right)}{Mol.\,mass}$$

Oxygen Balance	Risk
< -200	Low Risk
<-200, -100>	Moderate Risk
<-100, 100>	High Risk
<100, 200>	Moderate Risk
>200	Low Risk

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QUESTION 5

a) For acetaldehyde, the following was found in the literature:

TLV-STEL = 270 mg/m^3,

TLV-C = 300 mg/m^3,

Explain what these values mean. (4.5)

b) What is the effect of crystalline silica dust on human body? (2)

c) What is the effect of benzene or vinyl chloride monomer on humans? (3)

d) How would you characterise (from the toxicological point of view) the following group of chemicals (as a whole): acetone, toluene, ether, chloroform? (2.5)

e) What is the toxic effect of hydrogen cyanide? (2)

f) For Ethylene Dichloride, the following was found in the literature:

Oral LD_{50}= 770 mg/kg,

Dermal LD_{50}= 3890 mg/kg.

Explain what these values mean. (2)

g) Compare the effects (from the toxicological point of view) of NO_2 and CO_2. (3)

h) Discuss the effect of Cr^{3+} and Cr^{6+} on the human body. (3)

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