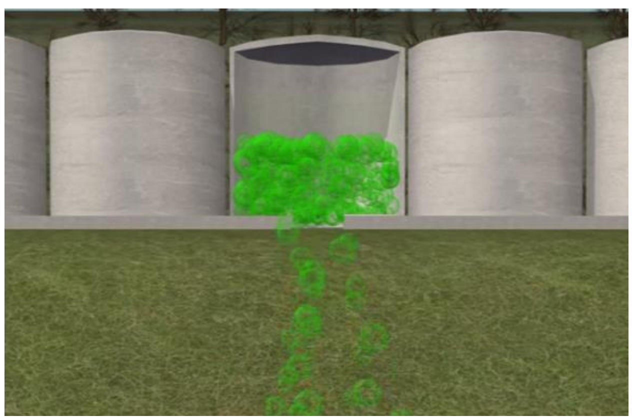
Fluid Mechanics

Safety Module 2: *Freedom Industries Released of Liquids from a Storage Tank in Charleston, WV on January 9, 2014*

Problem Statement: An above-ground tank, 20 ft. (6.1 m) tall and 20 ft.in diameter, at Freedom Industries in Charleston, WV was leaking a mixture of crude methyl cyclohexane methanol (MCHM) and polyglycol ethers through two small holes, 0.75" (19.05 mm) and 0.4" (10.16 mm) in diameter, near the floor caused by pitting corrosion. These chemicals traveled down a descending bank into the adjacent Elk River and also contaminated the surrounding soil. The secondary containment or the dike wall that was put in place, did not control the leak due to cracks and holes from disrepair. The nearly 11,000-gallon leak left around 300,000 people without drinking water.



Watch the Video: (*https://youtu.be/NtzvcbI6HFE*) shows leaking into Elk River.

Additional Content: (*https://www.youtube.com/watch?v=BeFokqIiBkM*) shows tank dismantling and pit holes.

Incident Report Available At: (*https://www.csb.gov/file.aspx?DocumentId=6036*) (Relevant pages: 1 to 7)

(a) It is important that chemical engineers understand what the accident was, why it happened and how it could have been prevented in order ensure similar accidents may be prevented. Applying a safety algorithm to the accident will help achieve this goal. In order to become familiar with a strategy for accident awareness and prevention, view the two YouTube videos shown above on the Freedom Industries release of liquids from a storage tank and fill out the following algorithm. See definitions on the last page. If necessary, view the incident report.

Safety Analysis of the Incident

Activity: ____

____

Hazard: ____

____

Incident: ____

Initiating Event: ____

Preventative Actions and Safeguards: ____

____

Contingency Plan/ Mitigating Actions: ____

____

Lessons Learned: ____

____

Additional Information

Assume that the concentration of MCHM in the fluid exiting the tank is much higher that the concentration of polyglycol. Mass flow rate of MCHM in the river before mixing is negligible. Assume the density of the liquid, ρ, in the tank to be constant and equal to 867 $\frac{kg}{m^3}$. Discharge Coefficient, C_o, for both the holes is 0.61.

(b) At t = 0 the corrosion pitted spots popped open and the liquid began to flow out of both holes at the bottom. If the height of fluid in the tank is initially 18 feet (5.49 m), calculate the volumetric flow out of each hole at t = 0. The gauge pressure inside of the tank above the fluid is $P_g = 8\ kPa$ and the pressure outside the holes is 101kPa (1 atm).

(Hint: First solve for exit velocity of liquid using Bernoulli's equation. Then multiply exit velocity with discharge coefficient to incorporate frictional losses.)

Is your answer for part (e) in the range 0.00200 m^3/s to 0.00300 m^3/s? If not, you may want to recheck your solution.

(c) Calculate the height of liquid in the tank as a function of time and solve for the time taken for 11,000 gallons (41.64 m^3) of liquid to leak from the holes.

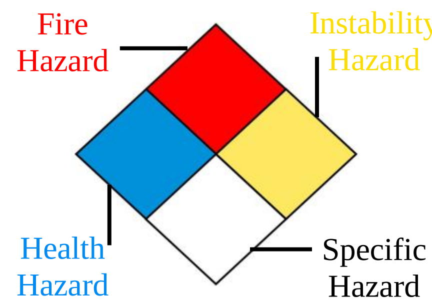
Is your answer for part (f) in the range 4 hours to 6 hours? If not, you may want to recheck your solution.

(d) Assuming the volumetric flow rate of the Elk River is 1,000 gals/minute (63.1 dm^3/s) and MCHM is instantaneously mixed in the river at the point of entry, calculate the concentration of MCHM at the point of entry in the river as a function of time.

Hint: Assume that initial concentration of MCHM in the river is zero and

$$Concentration\ at\ the\ entry\ point = \frac{mass\ flow\ rate\ of\ MCHM\ out\ of\ the\ vessel}{Volumetric\ flow\ rate\ of\ the\ river}$$

(e) Review the information in the NFPA Diamond tutorial. After reviewing the information, go through the Material Safety Data Sheet (MSDS) of MCHM and fill out the blank NFPA Diamond to the right for MCHM.



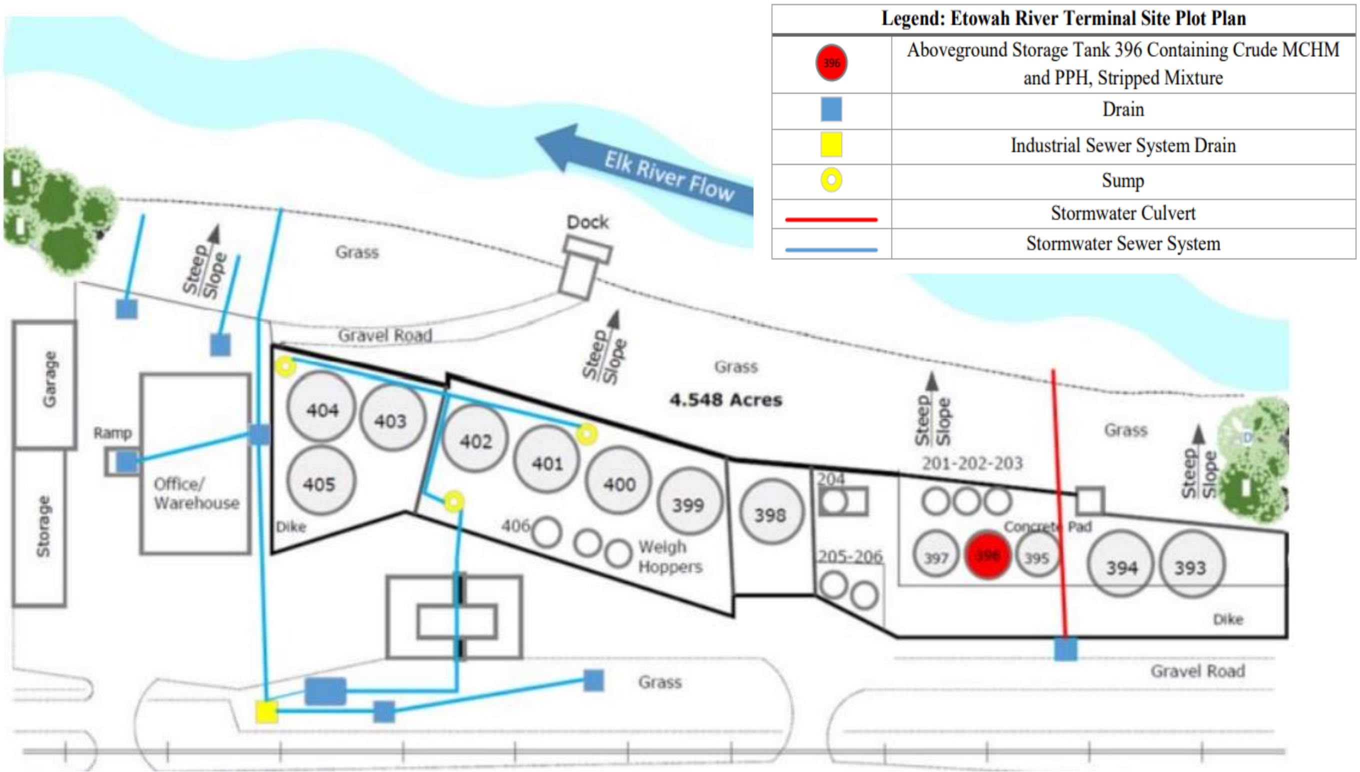
Parts **(f)-(h)** are based on industry practices used to assess process safety. For more information on process safety and its importance in chemical engineering, please visit the University of Michigan SafeChE website here. *It is recommended that professors only assign 1-2 of the following parts due to the similar nature of the questions.*

(f) Review the explanation of the components of a BowTie diagrams found here. After reviewing the information, create a BowTie diagram for the Freedom Industries incident.

(g) A HAZOP study is structured analysis of process design to identify potential vulnerabilities in a facility. Review the background on how to conduct a HAZOP study here before completing one for the following system. It is important to note that not all guidewords and parameters will be relevant for different systems. Some information is given here for guidance:

System to consider: Tank 396 used to store crude MCHM and PPH, stripped (see figure on next page)

Parameters to consider: Tank level, Tank Maintenance



(i) Fill out the HAZOP chart as shown in the tutorial. Some other information has been filled out here for you.

Guideword + Parameter = Deviation	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
More Level	Miscalculation in the empty space available in the tank while loading			
Other (*Corrosion* of the tank)	Storing corrosive chemicals for long periods of time without maintenance			

(ii) Write a short conclusion on some takeaways from completing a HAZOP for this system and recommendations you would make.

(h) A Layers of Protection Analysis (LOPA) is a semi-quantitative study to identify available safeguards and determine if the safeguards sufficiently protect against a given risk. Review the background on how to conduct a LOPA study here before filling the table for the system described in this module. Some information is given for guidance:

- Assume that the plant can only accept a minor risk
- The leak caused many nearby residents to be hospitalized

- The financial impact from cleanup, fines, and replacing the tanks can be assumed to be around $1 million

LOPA Study for Freedom Industries Leak		
Initiating Event	Cause:	Pitting corrosion
	Consequence:	Leak of tank contents into the nearby Elk River
	FOIE:	
IPL(s)	Description of IPL_1, IPL_2, ...	
	PFD = PFD_1 x PFD_2 x ...	
MCF	MCF = FOIE x PFD	
	Category of MCF:	
Severity	Impact:	Hospitalization of nearby residents, some business losses
	Category:	
Risk	Type of risk:	
	Acceptable / Unacceptable?	
If risk evaluated above is unacceptable, please continue below:		
Proposed IPL(s) (P-IPL(s))	Description of P-IPL_1, P-IPL_2, ...	
	P-PFD = P-PFD_1 x P-PFD_2 x ...	
MCF	MCF = FOIE x PFD x P-PFD	
	Category of MCF:	
Risk	Type of risk:	
	Acceptable / Unacceptable?	

(i) Describe what was the most unsettling to you about the incident.

Wolfram

Click here to download Wolfram CDF Player for free.

Click here to view CDF installation tutorial.

Click here to download Wolfram code for this module.

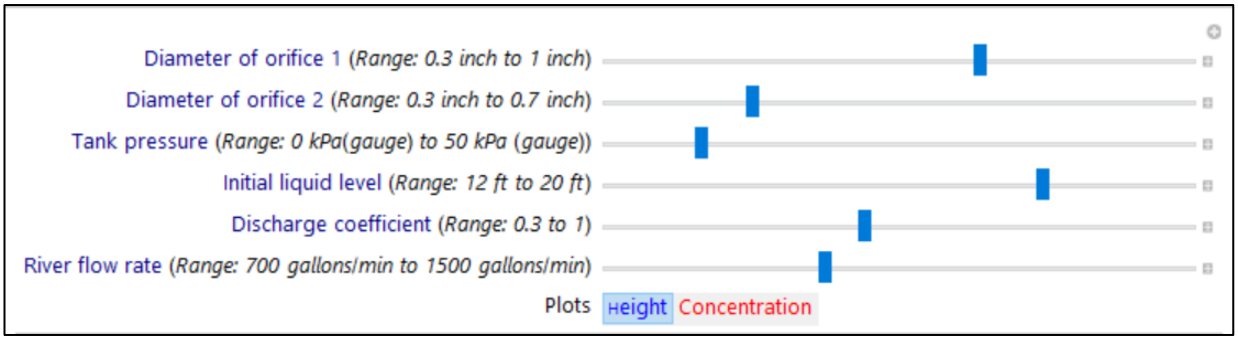


Figure 1.1 Wolfram Sliders

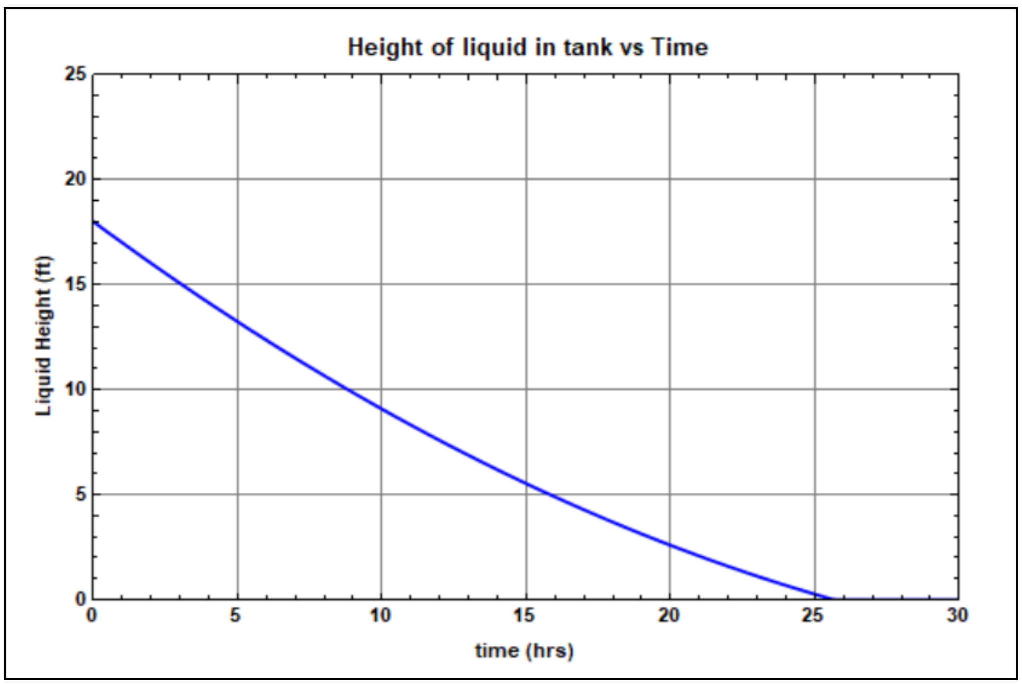


Figure 1.2 Sample Output: Trajectory of Height of liquid in the tank

(i) Vary *Discharge coefficient* C_o and *Gauge pressure*, and describe how these parameters affect the liquid height in tank?

(ii) Vary *River flow rate*, *Gauge pressure* and *Discharge coefficient* C_o and describe how these parameters affects the "time required for the concentration of MCHM in the river" to become zero.

(iii) Write a set of conclusions based on your experiments in (i) and (ii).

Definitions

Activity: The process, situation, or activity for which risk to people, property or the environment is being evaluated.

Hazard: A chemical or physical characteristic that has the potential to cause damage to people, property, or the environment.

Incident: What happened? Description of the event or sum of the events along with the steps that lead to one or more undesirable consequences, such as harm to people, damage to property, harm to the environment, or asset/business losses.

Initiating Event: The event that triggers the incident, (e.g., failure of equipment, instrumentation, human actions, flammable release, etc.). Could also include precursor events, (e.g., no flow from pump, valve closed, inadvertent human action, ignition). The root cause of the sum events in causing the incident.

Preventative Actions and Safeguards: Steps that can be taken to prevent the initiating event from occurring and becoming an incident that causes damage to people, property, or the environment. Brainstorm all problems that could go wrong and then actions that could be taken to prevent them from occurring.

Contingency Plan/ Mitigating Actions: These actions occur after the initiating event. They are steps that reduce or mitigate the incident after the preventative action fails and the initiating event occurred.

Lessons Learned: What we have learned and can pass on to others that can prevent similar incidents from occurring

BowTie Diagram: A qualitative hazard analysis tool through which potential problems and consequences associated with a hazard are studied through a pictorial representation. Necessary preventive and mitigating barriers are determined to reduce the process safety risk.

Hazard and Operability Study (HAZOP): A qualitative hazard analysis tool that uses a set of guide words to determine whether deviations from design or operating intent can lead to undesirable consequences. The existing safeguards are evaluated and if required, actions are recommended to mitigate the consequences.

Layer of Protection Analysis (LOPA): A semi-quantitative study that determines initiating event frequency, consequence severity, and likelihood of failure of independent protection layers (IPLs) to calculate the risk of a scenario. If the existing risk is intolerable, then additional IPLs are suggested to bring down risk to an acceptable level.

Module Specific for Freedom Industries Leak

Gauge Pressure: Difference between absolute pressure and atmospheric pressure

Discharge Coefficient: Frictional forces by walls of the leak acting on the moving fluid convert some of the kinetic energy of the liquid into thermal energy, thereby reducing velocity. To incorporate these frictional losses, velocity is multiplied by a discharge coefficient, C_o.

Table of Nomenclature

Symbol	**Name**	**Units**
C_o	Discharge coefficient	No units
P_g	Gauge pressure over the liquid in the tank	*Pa*
ρ	Density of MCHM	kg/m^3
Q_{river}	Volumetric flow rate of the river	*Gallons/min*
d_1	Diameter of orifice 1	*inch*
d_2	Diameter of orifice 2	*inch*
h	Height of liquid in the tank	*feet*
C	Concentration of MCHM at the entry point of the river	kg/m^3