Fluid Mechanics CHEG 341
Department of Chemical and Biomolecular Engineering
University of Delaware Fall 2020
Mini-Project # 1

Project Statement: In this project, you will be investigating a chemical safety incident from the DuPont facility in Belle, WV and providing your own additional calculations and interpretation to the case.

Learning Objectives:

- Apply Mass and Energy Balance concepts learned in first 3 weeks of course to evaluate a fatal chemical spill
- Perform a safety analysis of the incident
- Appreciate the role of fluid dynamics concepts in safety procedures in the chemical industry

Deliverable: You will prepare a brief written report. A completed report will include the following components (see the rubric on the last page and in canvas for the exact grading details, summarized in the following):

1. Executive Summary. A single paragraph briefly describing all of the enclosed components. Less than 1 pg.
2. Safety Analysis:
    - Must include summary of the incident using the for 7 points described in this document (organized in subheadings that are bolded and italicized)
    - Must include a BowTie Analysis and discussion of NFPA Diamond of phosgene
3. Scenario Analysis:
    - Must include complete discussion of all components listed in the scenario below (organized in subheadings that are bolded and italicized)
4. Personal Reflection
    - At least one paragraph addressing all of the questions listed in the prompt below
5. References
6. Appendix (optional)

Additionally, the completed report must include the following formatting components

- Times New Roman or Arial Font size 11; single or 1.5 spacing
- Header on the first page with three lines: your name, Mini-Project #1, the date submitted
- Page numbers in the bottom right corner of the footer
- Document has less than 5 glaring grammatical errors
- Section headers (#ed above) should be bolded. Subheaders bolded & italicized
- Any equations used must be listed and formatted in the document. They must be numbered sequentially (Eq 1, Eq2)
- Results should be summarized in graphs and tables. These should also be numbered sequentially (Fig.1, Fig. 2…).
    - Figures/Tables should be mentioned in the narrative. Each mention should be bolded. Example: "*The height of fluid in the tank was calculated using Eq. 4 and varies with time, as plotted in **Figure 2**.*"
    - Every Figure/Table must be accompanied by a descriptive caption
    - Figures/Tables should be inserted either as "floating" objects (off to the side of the text) OR in line immediately following the first mention and appear next to the first mention (examples of both in this prompt)
- References to any outside sources must be included and mentioned in appropriate places in the test. For example, you might write the following in the text: "*The NFPA Diamond of phosgene is shown in **Figure 1**.[3] The colors and numbers refer to different safety hazards such as…[4]*" Reference 3 is specific source information for phosgene, while reference 4 is generic information for NFPA Diamond. The full citation will be listed in the Reference section at the conclusion of the report. Follow the ACS style guide for reference formatting: https://pubs.acs.org/doi/full/10.1021/acsguide.40303

Incident details: On January 23, 2010 at the DuPont facility in Belle, WV, a 1-ton phosgene cylinder failed catastrophically. Two pounds of phosgene were released from a failed tube. One employee was sprayed across the face and chest, resulting in a lethal exposure in less than ten seconds. He died less than 36 hrs later. The U.S. Chemical Safety Board (CBS) and the DuPont company performed an extensive evaluation of this incident.

- Watch the summary video here (begins at 3:52): https://www.youtube.com/watch?v=ISNGimMXL7M
- Read the CBS incident report: https://www.csb.gov/dupont-corporation-toxic-chemical-releases/ and download the full report here (pg 48 – 88 and Appendix D cover the incident): https://www.csb.gov/assets/1/20/staff_draft_for_public_comment_final_corrected_reduced_file_size.pdf?13963

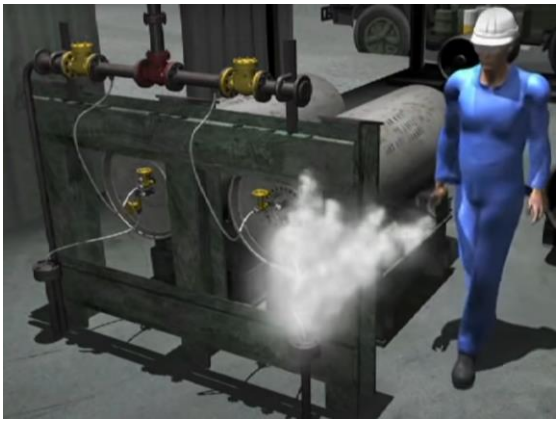

Figure 1*. Image from CBS video of the incident*

Safety Analysis: In the first section of your report, your task is to assemble a safety analysis of this incident. This should include descriptions of each of the following 7 points that are standard in describing a safety incident:

1. Activity	The process or activity for which risk to people, property or the environment is being evaluated.
2. Hazard	A chemical or physical characteristic that has the potential to cause damage to people, property or the environment
3. Incident	What happened? Description of the event or some of the events along with the steps that lead to one or more undesirable consequences, such as harm to people, damage to the property, to the environment, or asset/business losses
4. 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, and ignition. The root cause of the sum events in causing the incident.
5. Preventative actions, safe guards	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. Which ones were already in place and which ones were missing?
6. Contingency Plan/ Mitigating Actions	Steps that reduce or mitigate the incident after the preventative action fails and the initiating event occurred. Which were already taken and are there any missing?
7. Lessons Learned	What we have learned and can pass on to others that can prevent similar incidents from occurring

**Your report should have each of these points as a subheader bolded and italicized.*

In your description of the Hazard:

- Include a description of relevant chemical properties of phosgene and hazardous dosages to humans
- Include a NFPA Diamond for phosgene. Review the NFPA diamond purpose here: https://www.acs.org/content/acs/en/chemical-safety/basics/nfpa-hazard-identification.html

In your description of Lessons Learned:

- Include lessons stated by the CBS and Dupont as well as your own assessment. Make sure these are clearly delineated
- Include a BowTie diagram and include a description of the components you added. Read more about BowTie diagrams here: http://umich.edu/~safeche/bowtie.html

Scenario Analysis: In the second part of the report, we are going to consider two modified scenarios to appreciate the full danger of the phosgene cylinder.

Scenario I: Imagine a scenario where a full tank of phosgene is loaded onto the balance. The operator opens the top valve to add Nitrogen at 70 psig. Before the bottom valve is opened, the line breaks immediately at the joint to the cylinder, resulting in an open 1 in. diameter hole at the bottom of the tank. This is depicted in ***Figure 2***.

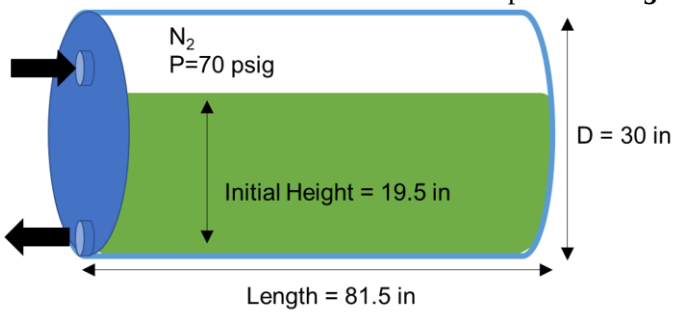

Figure 2. *Diagram of the simplified phosgene Scenario I for your calculations*

Assumptions:

- Density of liquid phosgene in the tank is constant 1.4 g/cm³
- The phosgene is stored in a DOT-106A500X Ton Container ASTM A-285 Grade A carbon steel cylinder. The internal volume of the cylinder has a diameter of 30 in. and length of 81.5 in.
- The 1 in. hole is on the side is immediately at the bottom of the tank and open to 1 bar Patm
- Atmospheric temperature: 55°F
- Ambient wind speed: calm, 1.5 m/s
- Boiling point of phosgene is 8° C (47° F)
- Full tank contains 2000 lbs of liquid phosgene that occupies ~70% of the tank volume
- N_2 continues to be supplied at 70 psig
- The discharge coefficient C_v is 0.61

Calculations to perform:

i. At t=0, phosgene begins to flow out of the hole in the tank at the bottom. If the fluid height is initially 19.5 in, calculate the volumetric flow rate out of the hole at t=0. *Hint: first solve for liquid velocity using the Bernoulli equation, then multiply exit velocity with the discharge coefficient to incorporate frictional losses*

ii. Using this volumetric flowrate (assumed to be constant as the tank drains due to the continually applied pressure), calculate how long it takes for the entire phosgene volume to exit the tank.

Scenario II: Imagine a scenario where a cylinder with same overall dimensions is oriented vertically as shown in ***Figure 3***. The top valve originally flowing N_2 (yellow) also disconnected so the tank is open to the atmosphere. The phosgene exit valve is at the bottom of the tank and disconnects at t=0, resulting in an open 1 in. diameter hole at the bottom of the tank. The same 2000 lbs of phosgene is present in the tank.

Calculations to perform:

iii. Calculate the height of the liquid in the tank as a function of time and solve the for total time for 2000 lbs of phosgene to escape from the tank. *Hint: first calculate the initial height based on the total volume present in scenario I.*

iv. Plot both the height of phosgene in the tank and the volumetric flow rate out of the hole as a function of time. How would these trends change with a different discharge coefficient? If there were still pressure of N_2 in the tank?

In your report, provide a written set of conclusions based on these calculations from both scenarios and describe why they are significant in addressing the potential safety concerns of this phosgene cylinder.

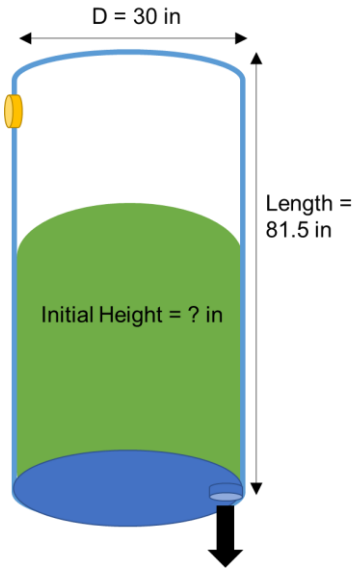

Figure 3. *Diagram of the simplified phosgene Scenario II for your calculations*

Format your report with three subheaders (bolded and italicized):

1. ***Height of Fluid in Tank Over Time***
   - Describe how the height changes over time in scenario II (include plot)
   - Describe how that would change (if at all) with varied P_{N2} or Cv
   - State how long until the height gets to 0 for both scenarios
2. ***Escaping Volumetric Flow Rate Over Time***
   - Describe how the exit volumetric flow rate changes over time (include plot of both scenarios)
   - Describe how that would change (if at all) with varied P_{N2} or Cv
3. ***Significance of These Estimations***
   - Compare the results of the 2 scenarios. Why calculate both of these? Why is an analytical solution of scenario I challenging? What does this tell you about pressurized cylinders?
   - Describe how tank height and exiting volumetric flow rate might be useful in designing safeguards around this tank
   - Describe how these estimations may be used to inform the potential hazard to an employee

Your main report must describe all of the calculations you performed and include representative equations in the report. You can use the optional appendix to include any longer information (spreadsheets, plugging in values etc).

Personal Reflection: The final section of the report should include a personal assessment of this incident and your calculations. It should answer the following questions:

- What was most unsettling to you about the incident?
- How did your knowledge of fluid dynamics help you assess the safety concerns?
- How did this change your perception of working with hazardous chemicals?
- What other information do you want to learn prior to entering a potential job to better understand how to avoid lethal safety incidents?

Rubric: This is the rubric that will be used to grade your project. Only the items listed below will be considered when evaluating the project. A completed assignment MUST have all of the items confirmed as complete; thus a "no credit" in any one of the items will mean a no credit for the project. Use the listed items as a checklist prior to submission to make sure that you receive credit for the assignment.

Overall Report

	Complete	**No credit**
Executive summary is only 1 pg with at least >=1 sentence about safety analysis, scenario analysis, reflection.		
Formatting is correct (times/arial 11, correct pg 1 header, footer all pages, sections bold, subsections bold/italics)		
Less than 5 glaring grammatical errors found		
Equations, Figures, Tables formatted appropriately		
References included and formatted correctly in main text and the concluding reference section		

Safety Analysis

	Complete	**No credit**
Correct 7 subheadings completed in good faith effort		
BowTie analysis performed and descriptive accompanying text included		
NFPA Diamond for phosgene and descriptive accompanying text included		

Scenario Analysis

	Complete	**No credit**
Correct 3 subheadings		
Accurate plot of fluid height in tank changing with time		
Time to empty tank in both scenarios correctly calculated and clearly stated		
Description of how fluid height changes with Cv and P_{N2} accurately included		
Accurate plot of escaping volumetric flow rate changing with time		
Description of how volumetric flow rate changes with Cv and P_{N2} accurately included		
Comparison of two scenarios included in significance		
Significance of calculations in designing safeguards discussed		
Significance of calculations evaluating risk discussed		

Personal Reflection

	Complete	**No credit**
Most unsettling thing about incident discussed		
Knowledge of applying fluid dynamics to access safety concerns discussed		
Change in perception about working with chemical hazards discussed		
At least one piece of additional knowledge identified as desirable prior to entering workforce		