Fluid Mechanics

Safety Module 3: *Barton Acetylene Service Company Gas Explosion, Perth Amboy, NJ, January 25, 2005*

Problem Statement: Acetylene generated by the reaction of calcium carbide and water flowed from the reactor to a number of storage tanks. Water flowed through a check valve into the generator. A check valve prevented acetylene from flowing out of the generator and down the water lines. An improper switching of water from city water to recycled water caused the pressure on the water side of the valve decreased allowing acetylene to flow through the misaligned check valve. The acetylene was then vented to the atmosphere, which reached an ignition source and exploded.

Figure 1

Watch the Video: (*https://www.youtube.com/watch?v=kOKBL1XHcB0*)

Incident Report Available At: (*https://www.csb.gov/acetylene-service-company-gas-explosion/*)

Encyclopedia: (*http://encyclopedia.che.engin.umich.edu/Pages/TransportStorage/Valves/Valves.html*)

(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 Chemical Safety Board video on the Barton Acetylene Service Company Gas explosion and fill out the following algorithm. See definitions on the last page. If necessary, view the incident report.

Safety Analysis of the Incident

Activity: ____

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Hazard: ____

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Incident: ____

Initiating Event: ____

Preventative Actions and Safeguards: ______________________________

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Contingency Plan/ Mitigating Actions: ______________________________

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Lessons Learned: ______________________________

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For parts (b) and (c), refer to: *http://encyclopedia.che.engin.umich.edu/Pages/TransportStorage/Valves/Valves.html)*

(b) Describe how a check valve is supposed to work.

(c) Discuss the advantages and disadvantages of using a check valve

(d) Estimate the valve constant (C_V) across the misaligned check valve. Assume that the recycled water line is 3" (0.0762 m) diameter extends 50m from the inlet at the acetylene generator to the outlet at the drain. Assume that $10m^3$ of acetylene escaped over the 66 minutes from generator startup to the time of the explosion and that the generator operates at gauge pressure of 5 psig (34.5 kPa). Assume that the coefficient of friction in the pipe is 0.1 and neglect all losses due to elbows, fittings, etc. Assume gas density to be 1.1 kg/m^3.

Hint: Solve for the pressure drop across the pipe and the valve using equation (1), then use the pressure drop across the valve to solve for the valve constant using equation (2).

(1) $$\Delta P = \rho \mu \frac{l}{d} \frac{v^2}{2}$$

(2) $$Q = C_V \sqrt{\frac{\Delta P_{valve}}{SG}}$$

Here,

ΔP = pressure difference across the pipe (Pa)

ρ = density of acetylene (kg/m^3)

μ = friction factor

l = length of the pipe (m)

d = diameter of the pipe (m)

Q = flow rate through the pipe ($\frac{m^3}{s}$)

C_V = Valve constant ($m^3/\sqrt{Pa}$ / s)

SG = specific gravity of acetylene with respect to air = $\frac{density\ of\ acetylene}{denisty\ of\ air} = 0.898$

About (2): The control valve equation relates the 'pressure difference across the valve ΔP_{valve}' and 'flow rate through the valve Q'. C_V is called the flow coefficient or the valve coefficient which describes the amount of fluid that can flow for a given pressure difference. So, the value of C_V can also, in a sense, be used to compare how misaligned the valve is.

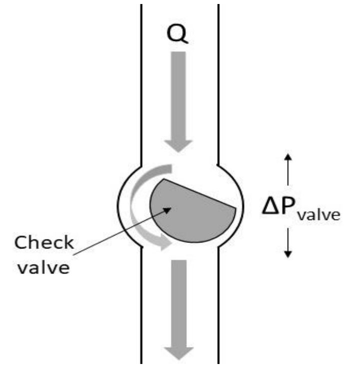
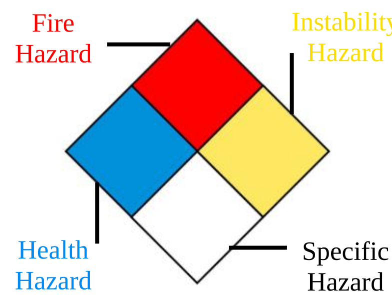


Figure 2 Schematic of the valve

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

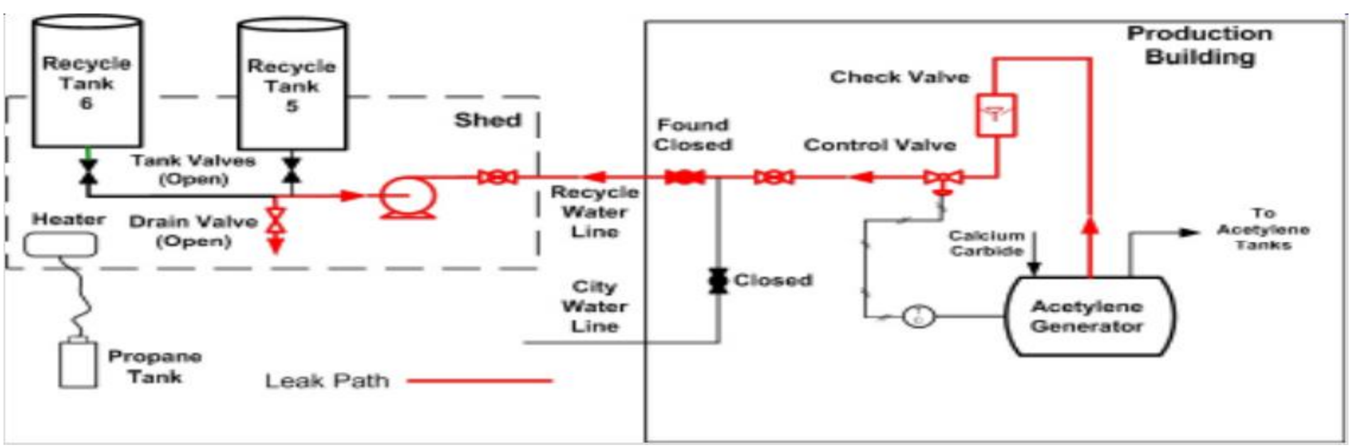


Parts **(f)-(h)** are based on industry practices used to assess process safety. For more information on process safety and its importance in chemical engineering, please visit the University of Michigan SafeChE website here. *It is recommended that professors only assign 1-2 of the following parts due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



Consider the scenario where recycled water is being supplied to the generator. A check valve is present in the recycle water line to prevent the back flow of acetylene gas.

Process parameters to consider: Flow of water into generator, Flow of acetylene, Water pressure

(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**
Less/No Flow of water into the generator	1. Closure of tank valves due to human error 2. Pump failure			
Reverse Flow of acetylene in the recycle water line	Decrease in water pressure			
Less Water pressure	Pump failure			

(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 out for the system described in this module. Some information is given for guidance:

- Assume that the plant can only accept a moderate risk
- Assume that an operator must manually switch to the recycle water line 90 times per year
- 3 fatalities were attributed to the explosion at this plant

LOPA Study for ASCO Explosion		
Initiating Event	Cause:	Operator error (Delay in turning on recycle water flow)
	Consequence:	Venting of acetylene to the wooden shed forming a flammable mixture
	FOIE:	
IPL(s)	Description of IPL_1, IPL_2, ...	Check Valve
	$PFD = PFD_1 \times PFD_2 \times ...$	
MCF	MCF = FOIE x PFD	
	Category of MCF:	

Severity	Impact:	Multiple Fatalities
	Category:	
Risk	Type of risk:	
	Acceptable / Unacceptable?	
If risk evaluated above is unacceptable, please continue below:		
Proposed IPL(s) (P-IPL(s))	Description of $P\text{-}IPL_1$, $P\text{-}IPL_2$, ...	
	$P\text{-}PFD = P\text{-}PFD_1 \times P\text{-}PFD_2 \times ...$	
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

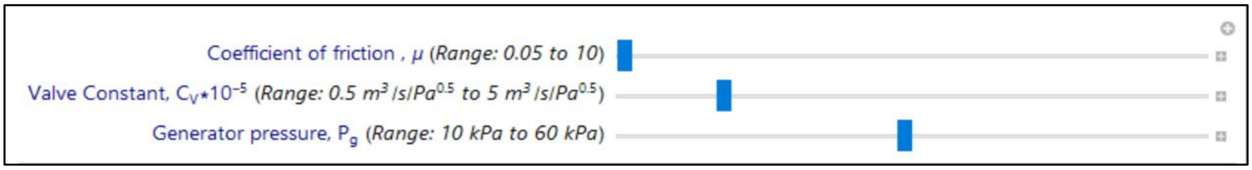


Figure 1.2 Wolfram Sliders

Sample Output Graph:

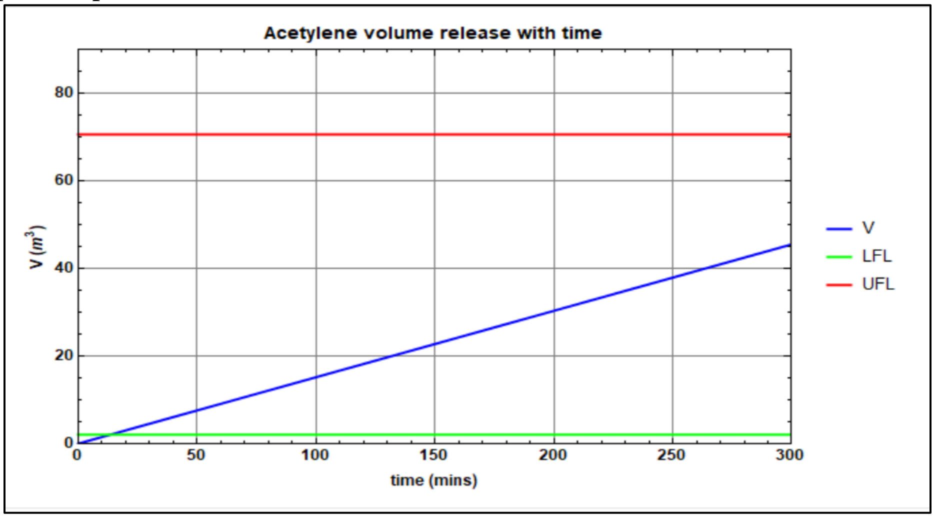


Figure 1.3: Trajectory of Volume of acetylene in the wooden shed

As mentioned in the report, the shed used to store the tanks was 15ft wide and 28ft long with a sloping roof varying between 6-8ft. Therefore, the volume of the shed (assuming the mean roof height of 7ft) is $2940ft^3$ or approximately $85m^3$.

For the acetylene-air mixture:
LFL = 2.4% → Volume for LFL = $0.024*85m^3 = 2.04m^3$
UFL = 83% → Volume for UFL = $0.83*85m^3 = 70.55m^3$

(i) Explain how leakage through the check valve varies with the *Valve Constant* C_v, the *Coefficient of friction* μ and the *Generator pressure* P_g.

(ii) Every valve is prone to leakage. This leakage puts an upper limit to the time for which there can be no water supply in the pipe. For the sake of this problem, let's say the valve constant C_v of a given valve is 0.5×10^{-5} $m^3/s/Pa^{0.5}$. Vary the slider for the generator pressure P_g, and explain how the 'maximum time for which the pipe can be left without water supply' changes.
(Hint: The maximum time for which the pipe can be left without any water supply is the time required to reach Lower Flammability Limit (LFL) in the Wolfram plot)

(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.

Table of nomenclature

Symbol	**Name**	**Units**
C_V	Valve constant	$m^3/\sqrt{Pa}$ / s
ΔP	Pressure difference across the pipe	kPa
P_g	Pressure in the acetylene generator	kPa
ρ	Density of acetylene	kg/m^3
μ	Coefficient of friction in the pipe	No units
l	Length of the pipe	m
d	Diameter of the pipe	m
Q	Volumetric flow rate	m^3/s
V	Volume of acetylene in the room	m^3
SG	Specific gravity of acetylene with respect to air	No units