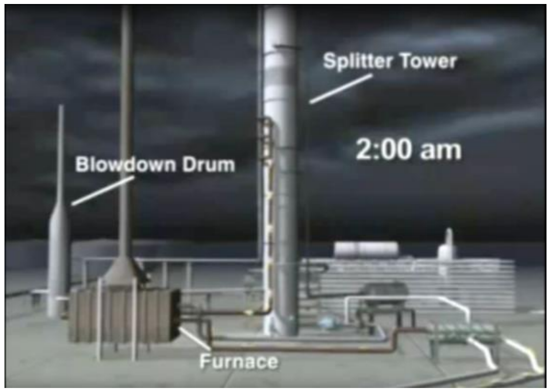
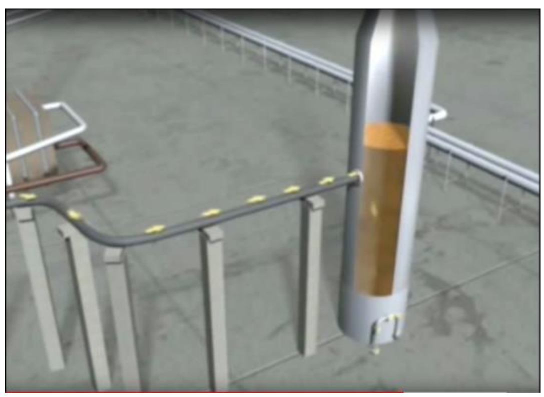
Separation Processes

Safety Module 3: *BP Explosion in Isomerization Unit, March 23, 2005*

Problem Statement: A distillation column at the BP Texas City refinery was overfilled with hydrocarbons such that the level reached 20 time the normal level (138 ft). This overfill produced an over-pressurization resulting in the release of flammables from the non-flare equipped vent stack. The release of flammable liquid and vapor was ignited by a spark source and led to an explosion and fire. Fifteen people were killed, 180 injured, and financial losses of more than $1.5 billion were incurred.





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

Final Investigation: (*https://www.csb.gov/file.aspx?DocumentId=5596)*
(Relevant Pages – Pg.21-25)

Safety Bulletin Report: (*https://www.csb.gov/file.aspx?DocumentId=5613*)

(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 BP explosion in the isomerization unit 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: ____

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Contingency Plan/ Mitigating Actions: ____

____

Lessons Learned: ____

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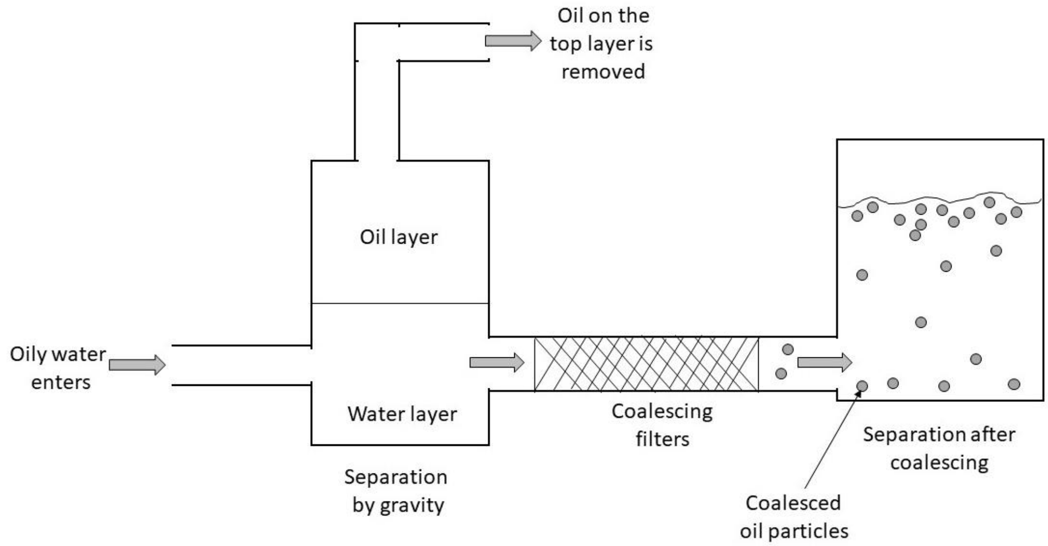
The CSB report says: "While liquid raffinate discharged out the top of the blowdown stack, it also flowed into the process sewer system and into the west diversion box and oil/water separator."
Due to the accident, large quantities of hydrocarbons have flown into the oil/water separator.

A typical oil/water separator consists of two stages. The first stage, where most of the hydrocarbon is recovered, consists of a settling chamber where separation is done by gravity. Given sufficient residence time, oil in the immiscible oil/water mixture accumulate on the water layer, which is then recovered from the top, as seen in Fig. 2.

In the second stage, coalescing filters are used to merge the remaining small oil droplets into larger spherical drops. These oil particles then rise to the surface, and are recovered in the same way as stage one. The larger the size of the droplets, the faster it rises to the surface, resulting in quicker separation!

For a better understanding of how an oil/water separator works, you can watch:

https://www.youtube.com/watch?v=Ge2SBKrVC8E



Schematic of an oil water separator

b) For a spherical oil droplet (density ρ_o) suspended in water (density ρ_w), the time taken to travel a distance 'h' vertically decreases with its radius 'R'. Prove this statement qualitatively.

Assume drag force on the spherical oil particle is given by $F_D = C_D A \frac{\rho_w v^2}{2}$,

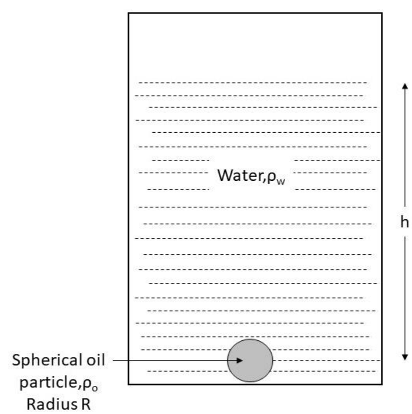
Where,

C_D *is the drag coefficient (dimensionless)*

A is the cross-sectional area of the sphere (m^2)

ρ_w *is the density of water* (kg/m^3)

v is the velocity of oil particle (m/s)



c) Typically, coalescing filters have a separation efficiency between 80 - 95%. In this plant, the separators are well maintained, and they operate at 90% efficiency given by,

$$Separator\ efficiency\ E = \frac{c_i - c_o}{c_i} \times 100$$

where, c_i is the inlet concentration of hydrocarbons in water, and c_o is the concentration of hydrocarbons in water at the outlet. In normal operation, c_i is 90 ppmw(mass/mass).

(i) Calculate the outlet concentration of hydrocarbons after separation by coalescing filters during normal operations.

(ii) Due to the excessive spill of hydrocarbons in the accident, the concentration of hydrocarbons in water passing through the filters was 500 ppmw. What is the concentration of hydrocarbon in water at the filter outlet, if the filter was operating at its usual 90% efficiency? Calculate the filter efficiency required to attain the same outlet concentration as in normal operations.

It was found that required separator efficiency is > 95% and the existing oil/water separator is not sufficient to deal with the excess hydrocarbons that went into the sewer lines. ***The refinery management has decided to clean the water by adding an adsorption column in the filter outlet.*** So, the separation will now take place in series arrangement with filter in lead. One of the choices for the adsorbate is powdered activated carbon (PAC).

d) The inlet concentration to the adsorbent is 50 ppmw. Calculate the amount of PAC that is required to bring down the concentration of hydrocarbons in water from 50 ppmw to 9 ppmw? Assume 50 m^3 of oil water mixture pass through the filters.

Additional information:

Langmuir isotherm for adsorption of hydrocarbons on powdered activated carbon is given by,

$$q_e = \frac{K_L C_e}{1 + bC_e}$$

With K_L = 2.58 (mg/g) and b = 0.0021

Where,

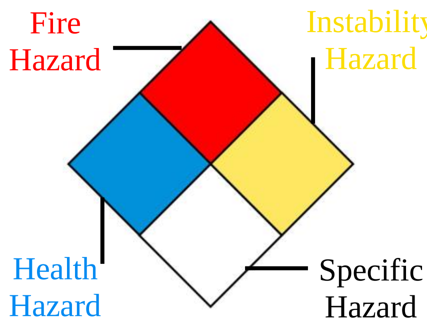
q_e is the amount of adsorbate per unit weight of adsorbent(mg/g).

C_e is the concentration of adsorbate in solution at equilibrium after the adsorption is complete(mg/L)

K_L is the amount of solute adsorbed/unit weight of an adsorbent in forming a complete monolayer on the surface (mg/g)

b is the constant related to the energy or net enthalpy of adsorption.

(e) Review the information in the NFPA Diamond tutorial. After reviewing the information, visit the CAMEO Chemicals website and fill out the blank NFPA Diamond to the right for octane.

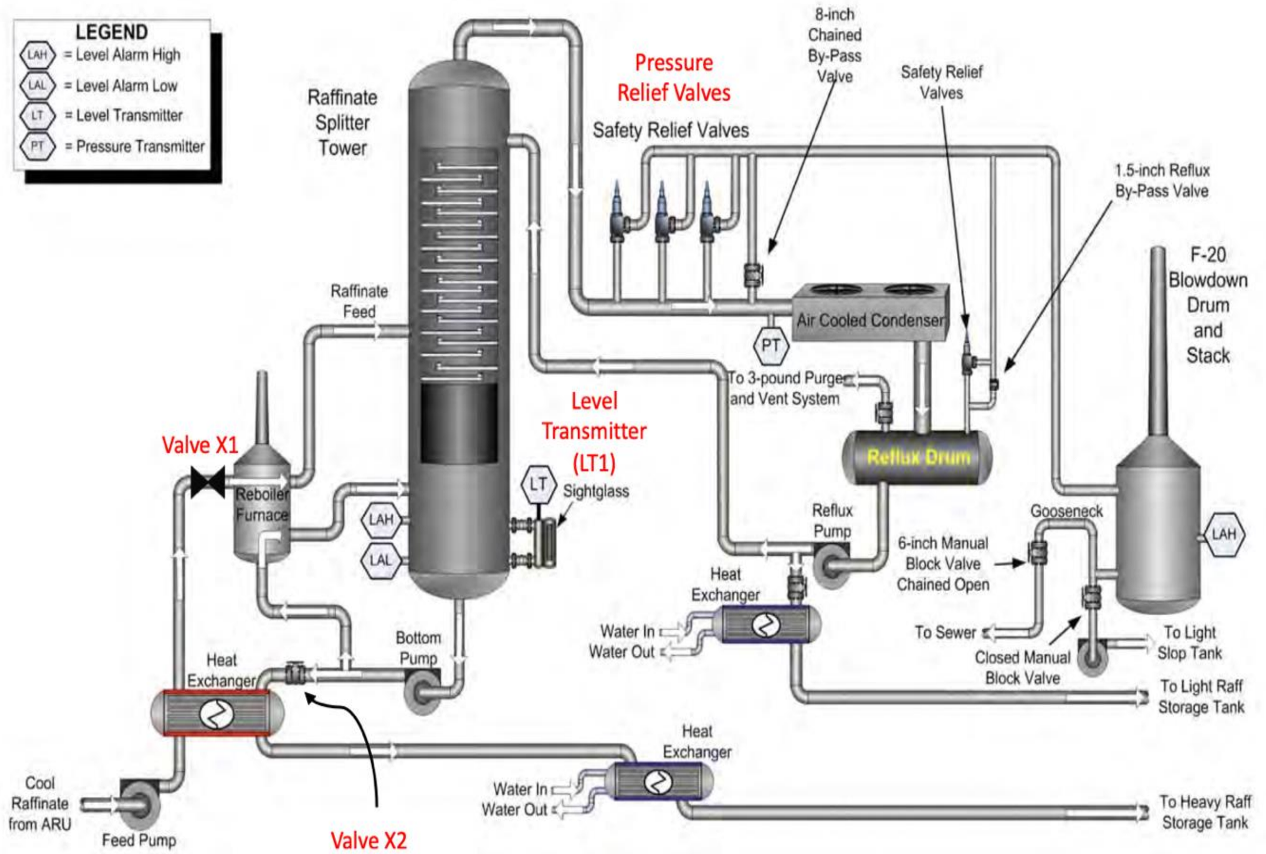


Parts (f)-(h) are based on industry practices used to assess process safety. For more information on process safety and its importance in chemical engineering, please visit the University of Michigan SafeChE website here. *It is recommended that professors only assign 1-2 of the following parts due to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

(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 below for guidance:

System to consider: Raffinate tower and blowdown drum of the BP Isomerization Unit



Consider the operation of the tower during startup. BP operators pump flammable organic liquid into the tower. As per startup procedure, valve X2 that controls flow out of the tower is initially closed. Once the level transmitter LT1 shows that the level has reached a specified value (e.g. 30%), the valve is opened. Consequently, the level is maintained at the specified value. Feed is heated in the reboiler furnace before entering the tower.

Process parameters to consider: Temperature of feed, Flow to tower, Pressure in the tower, Level in the tower, Flow to blowdown drum, level in blowdown drum

(i) Fill out the HAZOP chart as shown in the tutorial. Some information has been filled out here for you. Some boxes require you to fill in the blank.

Guideword + Parameter = Deviation	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
More (Higher) Temperature of feed	Increased heating in the reboiler furnace			
More Flow to the tower	Increased pumping of liquid due to failure of feed control valve X1			
More (Higher) Pressure in the tower	1. More heating causing more		1.Pressure Relief Valves	

	vapor flow to tower		2. High-pressure alarm connected to tower	
	2. High level of liquid in the tower			
More (High) Level in the tower	1. Increase in the flow rate of feed liquid into the tower	Increase in the level of liquid in tower → __________ → Liquid discharges into Blowdown Drum → ____________ → Liquid discharges into the atmosphere → ____________ → Ignition of vapor cloud → Explosion		
	2. Level transmitter (LT1) failure due to which operators are not alerted of the increasing level, and so bottom valve X2 remains in closed condition			
More Flow to blowdown drum	Overflow from the tower, because of which liquid discharges into the drum		High level alarm LAH connected to Blowdown Drum	
More (High) Level in the blowdown drum				

(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-qualitative study to identify safeguards available and determine if there are enough safeguards to prevent against a given risk. Review the background on how to conduct a LOPA study here before completing one for the following system. Some information is given for guidance:

- Assume that the plant can only accept a moderate risk
- Per the CSB report, the BP explosion caused 15 fatalities, 180 injuries, and financial losses of more than $1.5 Billion

Fill out the LOPA table and answer the question that follows.

LOPA Study for BP Explosion		
Initiating Event	Cause:	Level transmitter failure (basic process control system (BPCS) instrument loop failure)
	Consequence:	Overfilling of the tower and the blowdown drum, leading to spilling of ignitable liquid organic compounds
	FOIE:	
IPL(s)	Description of IPL_1, IPL_2, ...	
	$PFD = PFD_1 \times PFD_2 \times ...$	
MCF	MCF = FOIE x PFD	
	Category of MCF:	
Severity	Impact:	15 fatalities, 180 injuries, and losses of $1.5 Billion
	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, ...	
	$P\text{-}PFD = P\text{-}PFD_1 \times P\text{-}PFD_2 \times ...$	
MCF	MCF = FOIE x PFD x P-PFD	
	Category of MCF:	
Risk	Type of risk:	
	Acceptable / Unacceptable?	

Based on the LOPA study, do you think there is a need for installing more IPLs? If yes, think of the challenges involved in doing so. If you think the existing IPLs are sufficient to prevent a certain level of risk, how do you explain the explosion on the day of the incident?

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

Wolfram

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Click here to view CDF installation tutorial.

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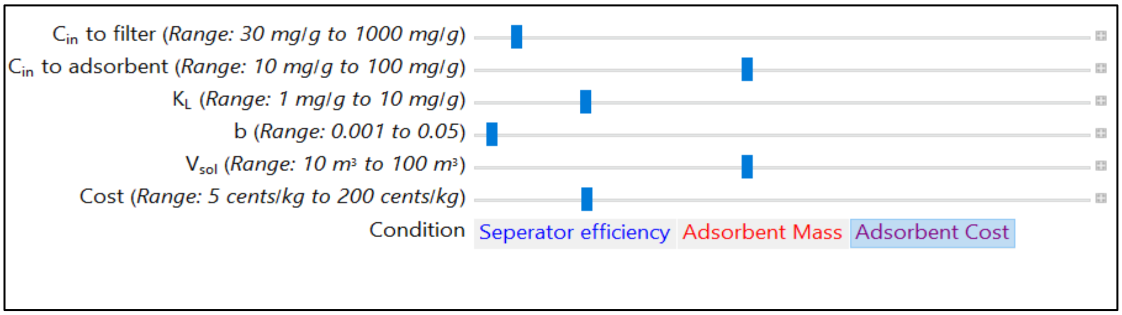

Fig 1.1 Wolfram Sliders

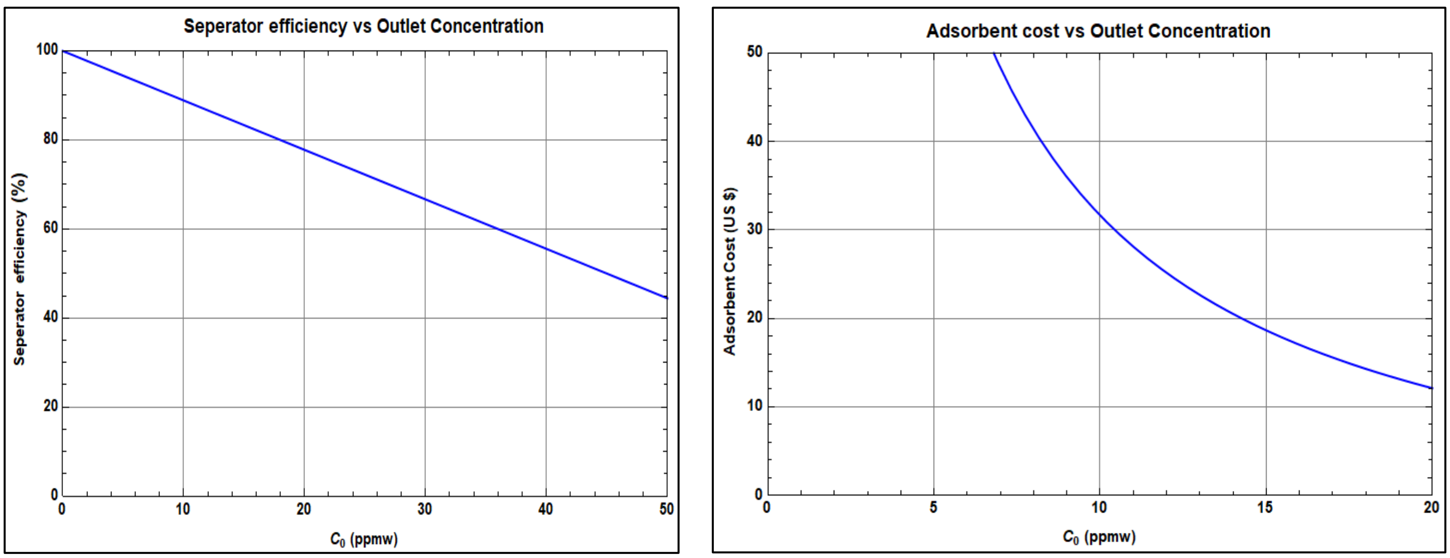

Figure 1.2 Sample Wolfram Graphs

(i) For a separator efficiency of 95%, what is the maximum inlet concentration at which an adsorption tower is not required. Assume maximum allowable outlet concentration is 15 ppmw?

(ii) Vary K_L and b and describe how these parameters affect the quantity of adsorbent required needed.

(iii) Using the *Additional information* given below, which of the three adsorbents (PAC, Bentonite or DC) is the best choice economically? Take inlet concentration of adsorbent to be 50 ppmw and outlet concentration to be 10 ppmw.

Additional information:

Alternatives to powdered activated carbon as an adsorbent are available. Langmuir parameters for these alternatives are given below:

Name of the adsorbent	K_L ***(mg/g)***	***b (mg/L)$^{-1}$***	**Cost per kg of adsorbent**
Powdered Activated Carbon (PAC)	2.58	0.0021	40 cents
Bentonite	7.12	0.0071	10 cents
Deposited carbon (DC)	9.23	0.0092	50 cents

Table of nomenclature

Symbol	**Name**	**Units**
ρ	Density	kg/m^3
R	Radius of oil sphere	mm or μm
h	Height to be travelled	m
g	Acceleration due to gravity	m^2/s
C_D	Drag coefficient	No units
E	Separator efficiency	No units
q_e	amount of adsorbate per unit weight of adsorbent	*mg/g*
C_e	concentration of adsorbate in solution at equilibrium	mg/L
K_L	amount of solute adsorbed/unit weight of an adsorbent in forming a complete monolayer on the surface	mg/g
b	constant related to the energy or net enthalpy of adsorption	No units

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.