Reaction Engineering and Design

Safety Module 4: *Dust Explosion at Imperial Sugar Company*

Note: For the shrinking core model for dust explosions, one can refer to Section 14.6.1 of

[1] H. S. Fogler, *Elements of Chemical Reaction Engineering*, 6th ed. Pearson, 2020.

Problem Statement: On February 7, 2008, combustible fine sugar was ignited at the Imperial Sugar Company causing an explosion. Because the fine granulated sugar has high surface area, it has the potential to rapidly burn and result in an explosion. Prior to the explosion the dust collection system was not working properly, as a result causing fine sugar that had spilled over on the floor and collected on the ceiling and piping became airborne. When the belt transport system was enclosed, the airborne sugar dust found an ignition source ignited. The explosion was fueled by the large accumulation of airborne sugar dust throughout the packaging plant. The fire and explosion caused 14 deaths and 38 injuries from life threating burns.

© US Chemical Safety Board

Watch the Video: (*https://www.youtube.com/watch?v=Jg7mLSG-Yws*)

Incident Report Available At: (*https://www.csb.gov/assets/1/20/imperial_sugar_report_final_updated.pdf?13902*)

(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 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: ____

____

Hazard: ____

Incident: ______________________

Initiating Event: ______________________

Preventative Actions and Safeguards: ______________________

____

Contingency Plan/ Mitigating Actions: ______________________

____

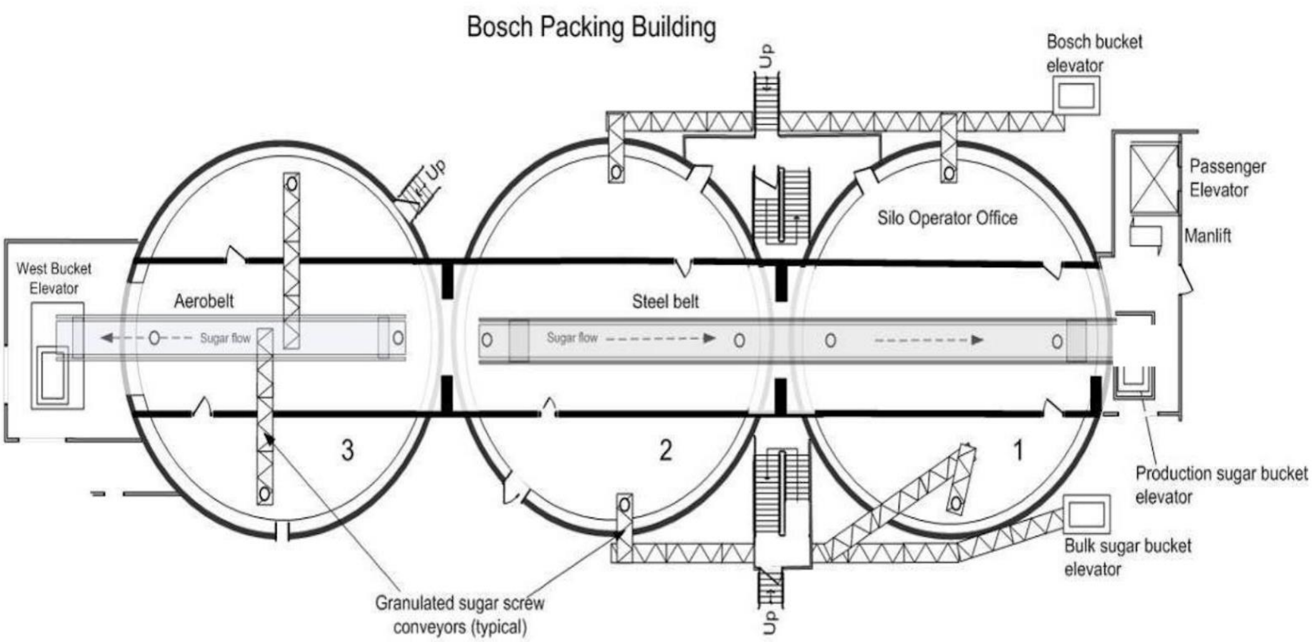
Lessons Learned: ______________________

____

(b) Review the information in the BowTie diagram tutorial. After reviewing the information, create a BowTie diagram for the Dust Explosion at Imperial Sugar Company.

(c) 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: Steel conveyor belt carrying granulated sugar shown in the figure:



Sugar flows out from the silos through chutes and is emptied onto the moving conveyor belt. The belt is surrounded by an enclosure, as indicated by the thick black lines around it. There is no ventilation over the belt, and the system behaves like a *closed system*.

Process parameters to consider: Concentration of sugar dust in air, functionality of conveyor belt, Quality of transported sugar

(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 (high) Concentration of Sugar Dust in the air inside the enclosure				
Other (Failure of Conveyor Belt*)*				
Quality – *More (high)* Concentration of Fine Particles in Transported Sugar	Excessive crushing of raw sugar			
Quality – *More* Clumps in Transported Sugar	1.Agglomeration of finer particles due to high pressure in silos (especially at the bottom) 2. Inadequate crushing of raw sugar			

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

(d) 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 sugar clumps block the chutes 25 times per year
- From the incident report, the dust explosion had a catastrophic impact of 14 fatalities and 36 injuries

LOPA Study for Dust Explosion at Imperial Sugar		
Initiating Event	Cause:	Operators failing to remove sugar clumps blocking the chutes
	Consequence:	Spilling of sugar dust, leading to an increase in the concentration of sugar dust in the surrounding air. The concentration of sugar dust can reach explosive levels.
	FOIE:	

IPL(s)	Description of IPL_1, IPL_2, ...	None
	PFD = PFD_1 x PFD_2 x ...	
MCF	MCF = FOIE x PFD	
	Category of MCF:	
Severity	Impact:	14 fatalities, 36 injuries, and extreme plant damage
	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?	

(e) 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.

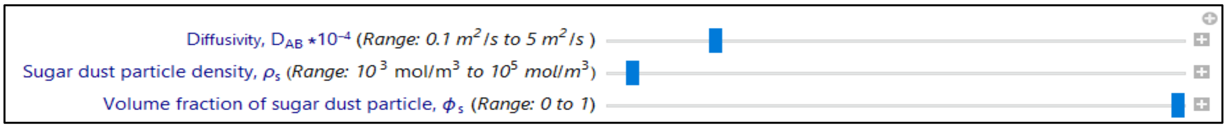


Figure 4.1 Wolfram sliders.

Sample output graph:

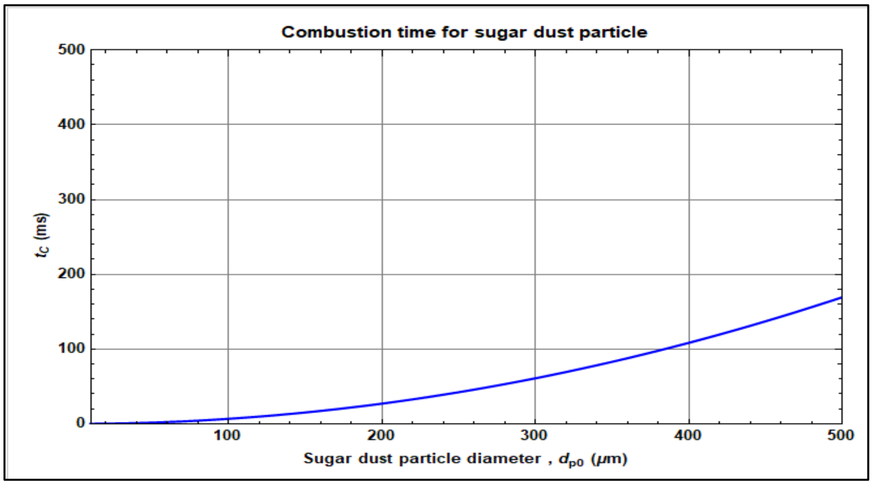


Figure 4.2 Burning time of sugar dust particle as a function of particle size.

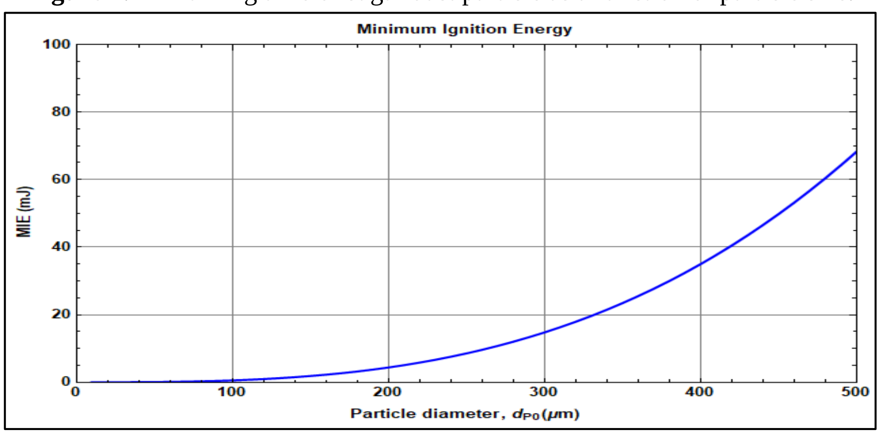


Figure 4.3 Minimum Ignition Energy (MIE) of sugar dust particle as a function of particle size.

(i) Vary the molar density of solid sugar dust particle, ρ_s and describe its effect on the burning time.

(Note: $t_c = \dfrac{d_{p0}^2 \rho_s \phi_s}{8 D_{AB} C_{A\infty}}$, take $C_{A\infty}$ ~ 8.5 mol.m^{-3})[1]

(ii) Vary the sliders and write a set of conclusions about the combustion time plot.

(iii) Use the Wolfram plot of Minimum Ignition Energy (MIE) vs particle diameter to compare the Minimum Ignition Energy (MIE) of a sugar dust particle of size 200 μm with that of size 400 μm and describe the threat that a dust cloud of smaller particle size causes.

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 Imperial Sugar Dust Explosion

Minimum Ignition Energy (MIE): The minimum energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure.

Table 4.1 Nomenclature

Symbol	**Description**	**SI Unit**
D_{AB}	Diffusivity between oxygen and sugar dust particle	m^2s^{-1}
d_{p0}	Diameter of sugar dust particle	m
$C_{A\infty}$	Bulk concentration of oxygen	$mol.m^{-3}$
t_c	Combustion (burning) time of sugar dust particle	s
ρ_s	Molar density of solid sugar dust particle	$mol.m^{-3}$
φ_s	Volume fraction of sugar dust particle	---
MIE	Minimum Ignition Energy	J