Fluid Mechanics

Safety Module 1: *Williams Owens Olefin Plant Explosion, June 13, 2013, in Geismar, LA*

Problem Statement: The Williams Owens Plant in Geismar, LA produces ethylene and propylene. The heat exchanger is attached to a fractionation column. Hot water on the tube side heats the propane and propylene on the shell side.

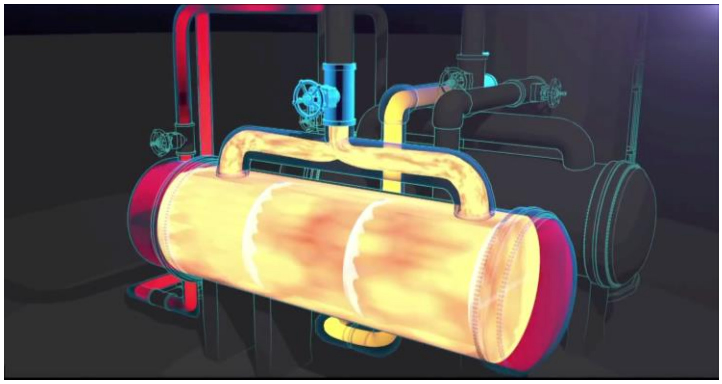

Figure 1 Heat exchanger at the Williams Owens Plant

Workers understood that oily tar tended to build up on the inside of the reboiler tubes, requiring periodic shut down for cleaning. The plant manager observed a significant decrease in flow rate over the past day and attributed it to tar build up on the tube walls. Workers decided to switch to the stand-by exchanger, which had not been in use for 16 months. Unknown to workers, this stand-by heat exchanger was detached from its pressure relief valve and contained liquid propane. When hot water was introduced into this heat exchanger, it violently ruptured and exploded within three minutes. The incident killed two workers and injured 167.

Watch the Video: (*https://www.youtube.com/watch?v=Z1KaykPaF8M*)

Incident Report Available At: (*https://www.csb.gov/file.aspx?DocumentId=6004*)
(Pages 5, 9, 11, 14, 15, 56)

(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 Williams Owens Olefin plant explosion and fill out the following algorithm. See definitions on the last page. If necessary, view pages 5, 9, 11, 14, 15, and 56 of 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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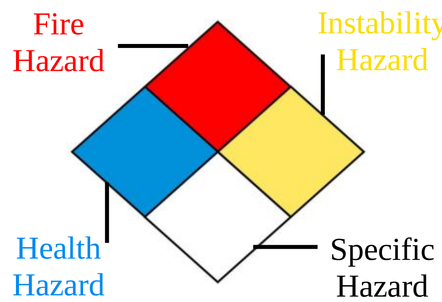
(b) Assuming the tar builds up uniformly on the inside of the tube, estimate the amount (i.e., thickness) of tar buildup necessary to reduce the water flow rate through the exchanger to 20% of its original flow rate. *For the sake of this problem assume the flow velocity is maintained constant with tar buildup.*

(c) 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 propane.

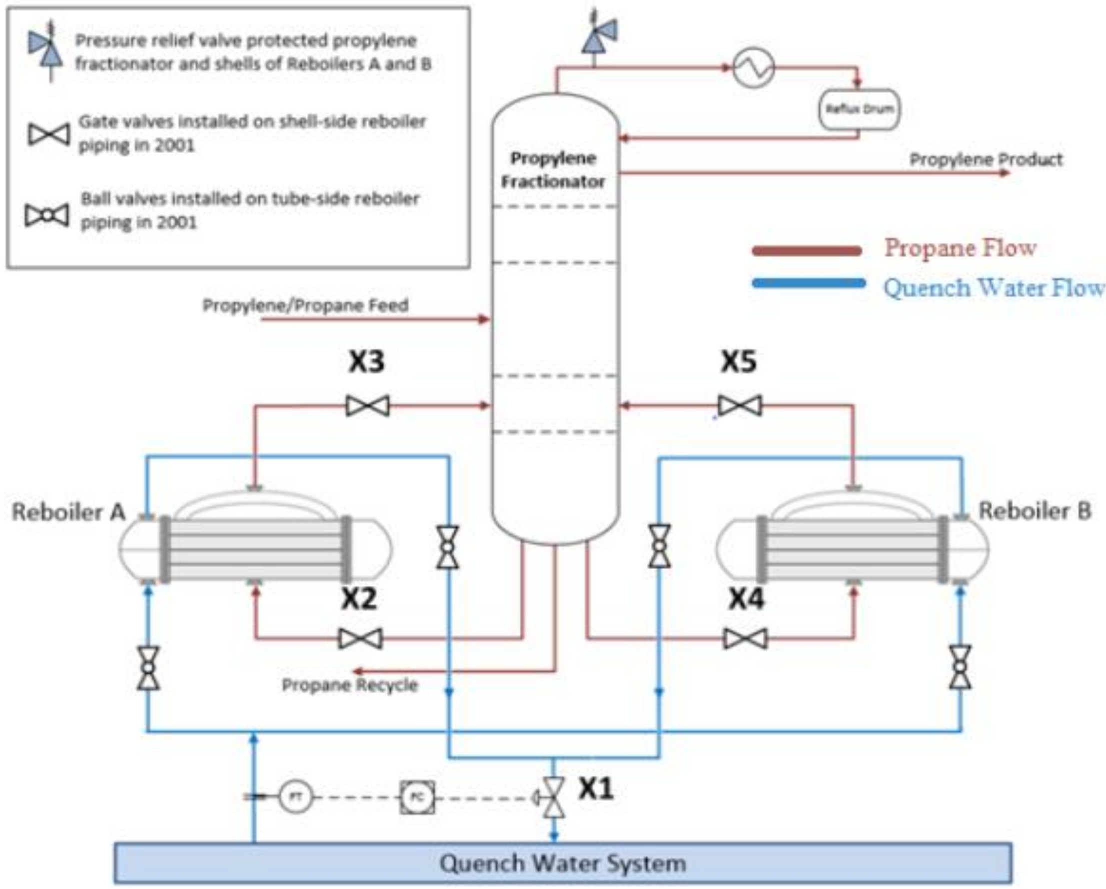


Parts **(d)-(f)** are based on industry practices used to assess process safety. For more information on process safety and its importance in chemical engineering, please visit the University of Michigan SafeChE website here. *It is recommended that professors only assign 1-2 of the following parts due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

(d) Review the explanation of the components of a BowTie diagrams found here. After reviewing the information, create a BowTie diagram for the Williams Owen Olefin Plant incident.

(e) 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: Bottom part of fractionator column that includes the active reboiler (A) and stand-by reboiler (B). Hot quench water flows through the tube side of the reboiler while propane flows through the shell side of the reboiler. Car seals were used to lock open the outlet valve of the process fluid when the reboiler is in operation. It is also assumed that the standard operating procedure used while switching from the operating reboiler to the standby reboiler is first opening the quench water, and then opening the process fluid valve.



Process Parameters to Consider: Temperature, Pressure, Flow of process fluid, Flow of quench water, Start-up

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

Guideword + Parameter = Deviation	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
More Flow of Quench Water into Reboiler A				
No/Less Flow of Process Fluid into Reboiler A	Closure of valve X2 due to human error			
More (High) Temperature of the process fluid in the shell side of Reboiler A	Closure of the outlet valve X3 isolating the reboiler from the only pressure safety valve			

More (High) Pressure in Reboiler A				
Other (Start-Up) of Reboiler B	Fouling in the operating reboiler			

(ii) When conducting a HAZOP, you will often find combinations of guidewords and parameters that describe a possible situation for the system that is not hazardous. For the given process parameters, give an example, explain why the situation is not hazardous, and describe another consequence that could occur. *HINT: Consider process efficiency*

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

(f) 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 the reboilers undergo maintenance once per year
- The explosion caused 2 fatalities and injured many more

LOPA Study for William Owens Explosion		
Initiating Event	Cause:	Operator Error (Followed incorrect procedure while switching reboilers)
	Consequence:	Increase in Pressure inside the reboiler leading to an explosion
	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:	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-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?	

(g) 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

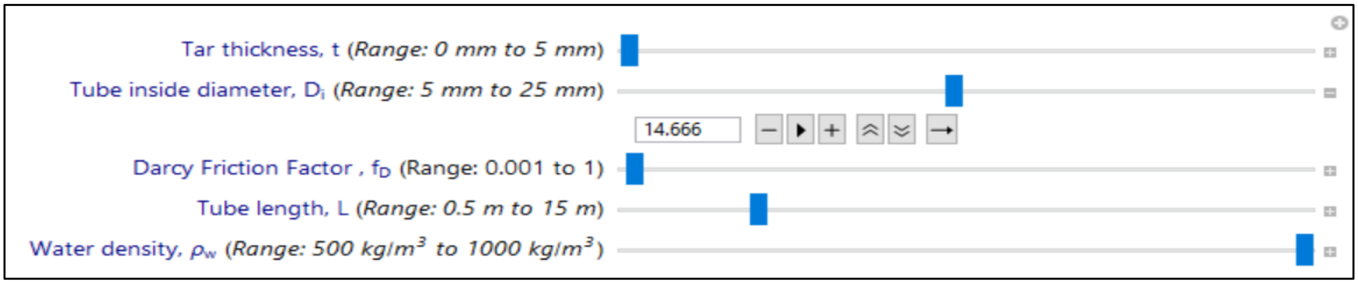


Figure 2.1 Wolfram Sliders

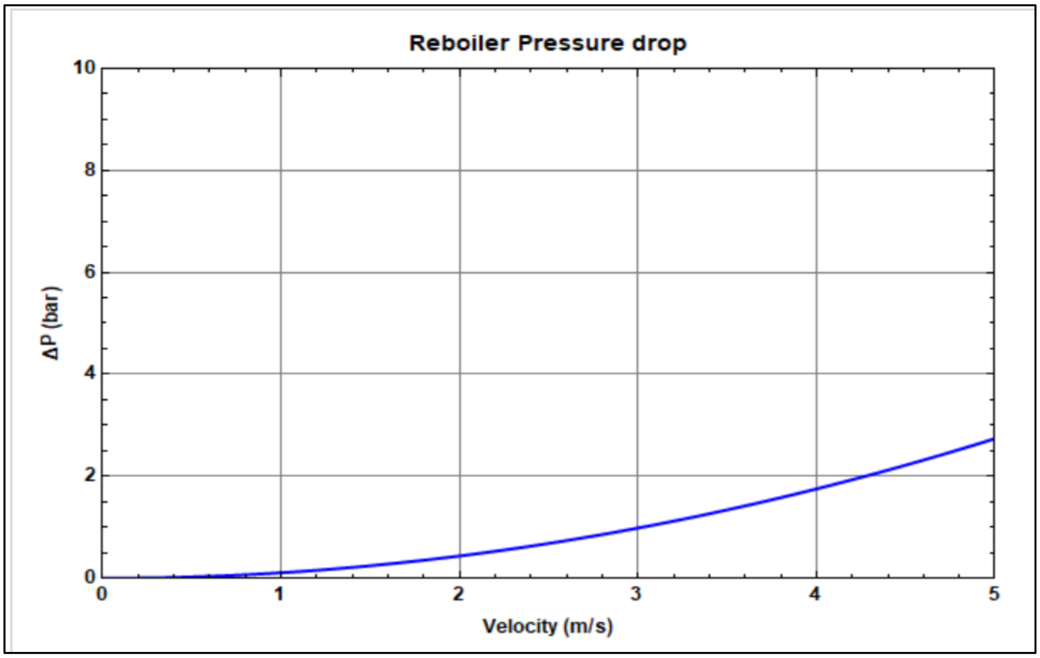


Figure 2.2 Sample Output: Flow velocity of water vs Pressure difference across the pipe

(i) Vary the sliders for *Tube inner diameter* D_i, *Tube length L* and *Darcy friction factor* f_D. How do these parameters affect the velocity of flow through the reboiler at a constant pressure difference?

(ii) Every reboiler has a minimum flow velocity that needs to be maintained and a maximum pressure difference that can be allowed. Given: Let's say for the reboiler in discussion, the minimum flow velocity v_{min} = 1.5 m/s and maximum allowable pressure difference ΔP_{max}= 2 bar.
For a tar build-up of thickness 5 mm, it can be seen that the flow is not in the permissible limits. Vary the sliders of *Darcy friction factor* f_D and *Tube inner diameter* D_i to find a set of conditions such that the flow can remain in the permissible limits.

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

Additional Information:
The reboiler used in the plant is a 6-tube pass heat exchanger with the following properties:

1. *There is a total of 3020 tubes in the reboiler meaning 503 tubes per pass.*
2. *The tubes are made of steel and are approximately 18.5 feet (5.64 m) long, with an inner diameter of 15.75 mm.*

(Data source: CSB Investigation report)

To better understand the structure of the reboiler let's look at a 2-pass heat exchanger (Ref: Figure 3) for simplicity,
If the pressure difference across the reboiler is ΔP_{total}, then the pressure difference across each pass is given by,

$$\Delta P_{single\ pass} = \frac{\Delta P_{total}}{number\ of\ passes} \tag{1}$$

If the flow rate of water through the tubes is Q_{total}, then the flow rate through each pass will be Q_{total}

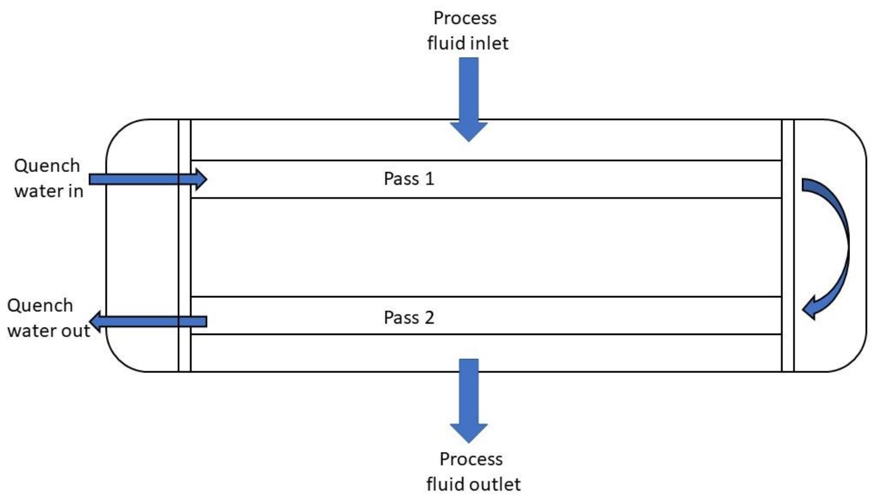


Figure 3.1 Schematic of a two-pass heat exchanger

The flow rate through each pass is Q_{total}, therefore the flow rate through each tube will be given by,

$$Q_{single\ tube} = \frac{Q_{total}}{number\ of\ tubes\ in\ one\ pass} \tag{2}$$

$\Delta P_{single\ pass}$ *will be the pressure difference across all the tubes in the pass.*

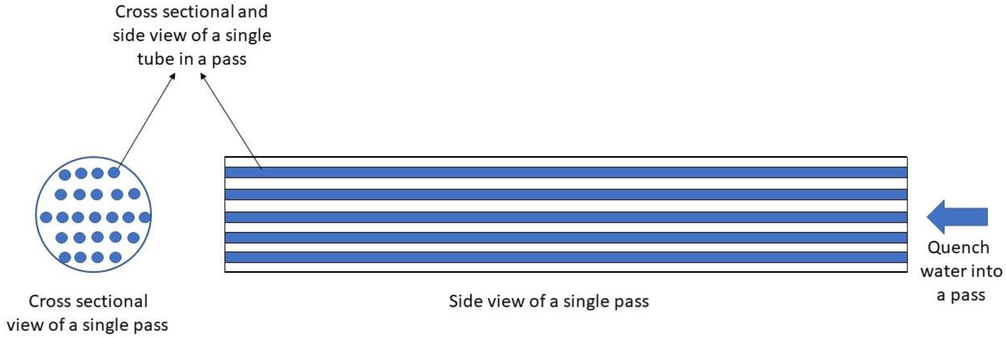


Figure 3.2 Schematic of a single pass

In conclusion for the 6-pass heat exchanger, in a single tube

$$Q_{single\ tube} = \frac{Q_{total}}{503}$$
$$\Delta P_{single\ tube} = \frac{\Delta P_{total}}{6}$$

Further, the average density of water in the heat exchanger is 976.16 kg/m^3 and assume the friction factor in the tubes to be 0.04.

The pressure difference and flow rate through a tube are related by the Darcy-Weisbach equation given by,

$$\Delta P = \rho_w f_D \frac{L}{D_i} \frac{v^2}{2} \qquad (3)$$

Table of Nomenclature

Symbol	**Name**	**Units**
Q	Flow rate	*m^3/s*
v	Velocity of flow	*m/s*
ΔP	Pressure difference	*bar*
D_i	Inner diameter of the tube	*mm*
t	Tar thickness	*mm*
f_D	Darcy friction factor	No units
L	Length of the tube	*m*
ρ_w	Density of water	*kg/ m^3*

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 to Williams Owens Olefin Plant Explosion

Fouling: The accumulation of unwanted material on solid surfaces to the detriment of function
Boiling Liquid Expanding Vapor Explosion (BLEVE)[†]: A BLEVE occurs when a vessel containing a liquid at a temperature above its atmospheric boiling point ruptures. The subsequent BLEVE is an explosive vaporization of a large fraction of the vessel contents that can be followed by combustion or explosion of the vaporized cloud. BLEVE occurs when an external heat source heats the contents of the vessel thereby increasing the vapor pressure in the vessel and reducing its structural integrity.

[†] From Crowl, D. A. and J.F. Louvar, *Chemical Process Safety with Applications,* Prentice Hall, Upper Saddle River, NJ.