HAZOP Tutorial

Section I: Introduction

A Hazard and Operability Study, commonly referred to as a HAZOP study, is a structured analysis of process design to identify process safety incidents that a facility is vulnerable to. A HAZOP study uses guide words to systematically determine possible failures that could result from operation of equipment outside of design conditions. This "out of design" condition can occur due to possible mal-operation or mal-function of individual items of equipment, instruments or control system.

A list of necessary actions and recommendations to improve the safety and mitigate the consequences of hazards will be prepared in the form of HAZOP Report.

This module includes a HAZOP study example for the explosion at the Caribbean Petroleum Company (CAPECO), as seen in the first Material & Energy Balance Module. A HAZOP study could have exposed flaws in the design and prevented the incident.

Section II: HAZOP Process

The first step in a HAZOP study is to select a piece of equipment and then identify each process parameter that is relevant to that equipment's operation. These process parameters may include temperature, pressure, flow rate, pH, concentration, viscosity, volume, etc. Figure 1 shows a tank selected as the piece of equipment to analyze. One of the process parameters is the inlet flow rate.

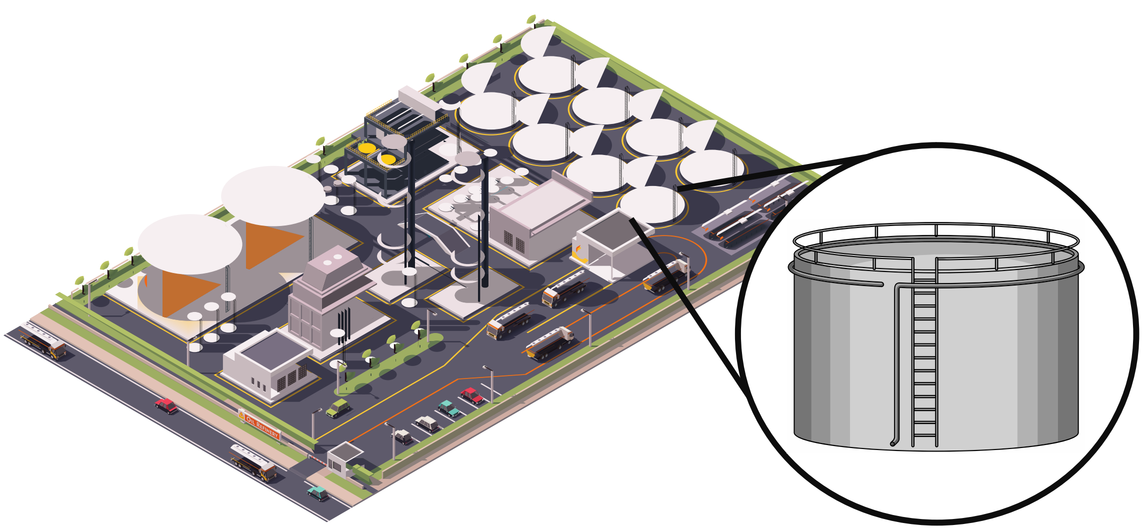

Figure 1. Select Equipment and Process Parameter

With the process parameter in mind, the next step is to use Guide Words to systematically consider all abnormal operating scenarios. Appropriate Guide Words must be systematically applied to the process parameter to analyze whether or not the scenario is possible. The HAZOP team then look into the Cause, Consequence, Safeguards provided, and any additional safeguard required. The guide words can be seen below in Table 1.

Table 1. HAZOP Guide Words and Definitions

No.	Guide Words	Meaning	Process Parameter Deviation
1	No or Not	Did not occur to any extent	Flow
2	More	Quantity greater than expected	Flow, Temp, Pressure, Level
3	Less	Quantity less than expected	Flow, Temp, Pressure, Level
4	As Well As	Occurred in addition to	Quality
5	Part Of	Occurred to some extent, less than whole	Quality
6	Reverse	Opposite of design intention	Flow
7	Other Than	Complete Substitution	Quality
8	Early	Event occurrence sooner than expected	Applicable mainly for Batch Process
9	Later	Event occurrence later than expected	Applicable mainly for Batch Process
10	Before	Step occurred too soon in the sequence	Applicable mainly for Batch Process
11	After	Step occurred too late in the sequence	Applicable mainly for Batch Process
12	Others	General issues	Start-up/Shut-down, Corrosion, Leak, Utility failure (Power, Instrument Air, Cooling water) etc.

Using the guideword and parameter, we can analyze the deviations from normal operating conditions that the equipment could incur, as described by the graphic below. A deviation is any divergence from normal operating behavior. For example, a potential deviation in a tank is high pressure.

Guide Word + Parameter → Deviation[5]

After considering all deviations that could result from one guide word, the next guide word is addressed. The intent is to identify every deviation caused by a parameter paired with a guide word. Appendix A shows some of the possible causes of deviation.

Note: Not every guide word will apply to each scenario. For example, there is no physical meaning to a temperature reading being “part of”.

Section III: HAZOP Implementation

The HAZOP study forces engineers to consider all deviations from normal operating conditions and the associated hazards. After completing a HAZOP study, the next step is to implement protections or safeguards. Each safeguard must be capable of independently preventing the deviation.

Guide Word + Parameter $\nrightarrow$ Deviation

Safeguard

While HAZOP is a qualitative study, a Layer of Protection Analysis (LOPA) is semi-quantitative. Engineers implement protections to the equipment that prevent the mathematically highest impact scenarios in terms of risk and probability. Please see the LOPA Tutorial for more information here.

A typical HAZOP worksheet looks like this:

GUIDEWORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS

Note: *Following causes are not considered in HAZOP study:*

1. Simultaneous occurring of two unrelated incidents.

2. Simultaneous failure of more than one independent protection devices

3. Natural Calamity (Earthquake, Flood, Cyclones etc.)

4. Sabotage

Section IV: HAZOP Application to CAPECO Example

In the CAPECO explosion, the main gasoline storage tank was full, so an additional shipment of gasoline had to be transferred to four smaller tanks through a manual process. One of the tanks had a broken level transmitter so fill time was manually calculated and unfortunately overestimated. The tank overfilled and the gasoline found a spark and rapidly exploded. Watch the video here: https://www.youtube.com/watch?v=41QMaJqxqIo.

This section will investigate how a HAZOP study performed at the CAPECO facility could have exposed flaws in the facility's protective systems. Exposing these hazards may have resulted in actions to close gaps and prevent the tank overfill that resulted in the catastrophic explosion.

1. Identify System

The system in the CAPECO example is the secondary gasoline storage tank. This is the vessel overfilled and resulted in the explosion.

2. Identify Process Parameter

The process parameter is the inlet flow rate from the tanker vessel to the gasoline storage tank.

3. Apply Guide Word

Guide Word #1: ***No***

The engineer would first consider a scenario where there was ***no*** *flow from the tanker vessel to the storage tank. They would need to assess what a* ***no*** *flow scenario means and what are the safety implications. In order to address this scenario, consider the HAZOP worksheet below.*

GUIDEWORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
No	Low tank level	Inlet Line Rupture Inlet Line blockage	Release of flammable material	Float level gauge	Alarmed pressure transmitter on inlet

Guide Word #2: ***More***

A guide word ***more*** *would describe an incident where more gasoline than expected was offloaded into the tank. This was the scenario that occurred in the CAPECO example.*

GUIDEWORD	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
More	Overfill tank	Level Transmitter failure Miscalculate time to fill tank	Release of flammable material	Float Level Gauge Dike	Automatic flow diverter Total organic content detector in Water Treatment facility

This tank was not equipped with an automatic overfill protection system that would have stopped the flow as soon as it detected overfill or diverted the flow to another tank. After considering each deviation caused by ***more*** *flow, the engineers at the CAPEO facility may have determined that their facility is ill-equipped to measure and react to additional flow.*

More + Inlet Flow Rate → Overfill Tank

4. Gap Identification & Next Steps

Once we have identified all hazards, the next step is to apply a Layers of Protection Analysis (LOPA) to the highest risk and impact scenario. These safeguards could include any of the following:

1. *Functional level transmitter communicating with an automatic flow diverter*
2. *Alarm system alerting when there is a high level in the tank*

3. *Alternative secondary containment besides the diked region*
4. *Gas detector in the vicinity of the tank farm*
5. *Total organic carbon (TOC) composition detectors on inlet to water treatment facility*

If implemented, each of these layers of protection could have prevented this event from occurring. More information on how to conduct a LOPA can be found in the LOPA Tutorial here.

References

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[2] Maher, Steven T, et al. "Preparing for a Successful HAZOP/LOPA." *AIChE 2018 Spring Meeting*, American Institute of Chemical Engineers, 22 Apr. 2018, www.rmpcorp.com/wp-content/uploads/2018/04/513595.PreparingForASuccessful.HAZOP_.LOP A_.GCPS-2018.P APER_.Rev_.2018.04.25.pdf.

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Appendix A

Deviation	**Typical causes**
No flow	Valve Closed; Pump failure; Incorrect pressure difference, Major leakage etc
Less flow	Pump cavitation, Fouling, partial blockage etc

More flow	Valve full open, Increased pump speed, Increased pressure differential etc
Reverse flow	Pump trip, Incorrect differential pressure, NRV passing
High Pressure	Closed discharge, pressure control failure, excessive re-boiling, loss of reflux
Less pressure	Pump/compressor failure
More temperature	Heater control failure, Runaway reaction
Less temperature	Loss of heating, Fouled exchanger
More level	Level control failure, More input than output
Less level	Level control failure, Less input than output
Composition Change	Leaking exchanger tubes, Feed Change, Wrong additives, additional reactions

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