HAZOP
Hazard and Operability Study

PROCESS HAZARD ANALYSIS TECHNIQUES

Risk management involves process hazard analysis (PHA) as the first step to commence the process of hazard identification. Many methods exist for conducting PHA, such as:

- What-if checklist
- Fault tree analysis (FTA)
- Failure mode and effect analysis (FMEA)
- Cause–consequence analysis
- Event tree analysis (ETA)
- Hazard and operability analysis (HAZOP).

A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing *process* or *operation* in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation.

The HAZOP technique was initially developed to analyze *chemical process* systems, but has later been extended to other types of systems and also to complex operations and to software systems.

A HAZOP is a qualitative technique based on *guide-words* and is carried out by a multi-disciplinary team (*HAZOP team*) during a set of meetings.

When to perform a HAZOP?

The HAZOP study should preferably be carried out as early in the design phase as possible - to have influence on the design. On the other hand; to carry out a HAZOP we need a rather complete design. As a compromise, the HAZOP is usually carried out as a final check when the detailed design has been completed.

A HAZOP study may also be conducted on an existing facility to identify modifications that should be implemented to reduce risk and operability problems.

When to perform a HAZOP? - (2)

HAZOP studies may also be used more extensively, including:

- At the initial concept stage when design drawings are available
- When the final piping and instrumentation diagrams (P&ID) are available
- During construction and installation to ensure that recommendations are implemented
- During commissioning
- During operation to ensure that plant emergency and operating procedures are regularly reviewed and updated as required

HAZOP background

- The basis for HAZOP was laid by ICI in 1963 and was based on so-called "critical examination" techniques
- First guide: "A Guide to Hazard and Operability Studies", ICI and Chemical Industries Associations Ltd. 1977.
- First main textbook: Kletz, T. A.: *"Hazop and Hazan - Identifying and Assessing Process Industry Hazards"*, Institution of Chemical Engineers.
- See also: Kletz, T. A.: "Hazop – past and future". *Reliability Engineering and System Safety*, **55**:263-266, 1997.

Types of HAZOP

- Process HAZOP
  - The HAZOP technique was originally developed to assess plants and process systems
- Human HAZOP
  - A “family” of specialized HAZOPs. More focused on human errors than technical failures
- Procedure HAZOP
  - Review of procedures or operational sequences
    Sometimes denoted SAFOP - SAFe Operation Study
- Software HAZOP
  - Identification of possible errors in the development of software

HAZOP team and meetings

Team members and responsibilities

- **HAZOP team leader**

  Responsibilities:

  - Define the scope for the analysis
  - Select HAZOP team members
  - Plan and prepare the study
  - Chair the HAZOP meetings
    - Trigger the discussion using guide-words and parameters
    - Follow up progress according to schedule/agenda
    - Ensure completeness of the analysis

The team leader should be independent (i.e., no responsibility for the process and/or the performance of operations)

Team members and responsibilities (2)

- **HAZOP secretary**
  Responsibilities:
  - Prepare HAZOP worksheets
  - Record the discussion in the HAZOP meetings
  - Prepare draft report(s)

Team members

- **HAZOP team members**

  The basic team for a process plant will be:

  - Project engineer
  - Commissioning manager
  - Process engineer
  - Instrument/electrical engineer
  - Safety engineer

  Depending on the actual process the team may be enhanced by:

  - Operating team leader
  - Maintenance engineer
  - Suppliers representative
  - Other specialists as appropriate

How to be a good HAZOP participant

- Be active! Everybody's contribution is important
- Be to the point. Avoid endless discussion of details
- Be critical in a positive way - not negative, but constructive
- Be responsible. He who knows should let the others know

HAZOP meeting

Proposed agenda:

1. Introduction and presentation of participants
2. Overall presentation of the system/operation to be analyzed
3. Description of the HAZOP approach
4. Presentation of the first node or logical part of the operation
5. Analyze the first node/part using the guide-words and parameters
6. Continue presentation and analysis (steps 4 and 5)
7. Coarse summary of findings

Focus should be on potential hazards as well as potential operational problems

Each session of the HAZOP meeting should not exceed two hours.

HAZOP recording

The findings are recorded during the meeting(s) using a *HAZOP work-sheet*, either by filling in paper copies, or by using a computer connected to a projector (recommended).

The HAZOP work-sheets may be different depending on the scope of the study - generally the following entries (columns) are included:

1. Ref. no.
2. Guide-word
3. Deviation
4. Possible causes
5. Consequences
6. Safeguards
7. Actions required (or, recommendations)
8. Actions allocated to (follow-up responsibility)

Process HAZOP

Prerequisites

As a basis for the HAZOP study the following information should be available:

- Process flow diagrams
- Piping and instrumentation diagrams (P&IDs)
- Layout diagrams
- Material safety data sheets
- Provisional operating instructions
- Heat and material balances
- Equipment data sheets Start-up and emergency shut-down procedures

Requirement of updated documents

Documents for a new or existing facility must be available long before a HAZOP study. The availability of these documents saves time during these sessions:

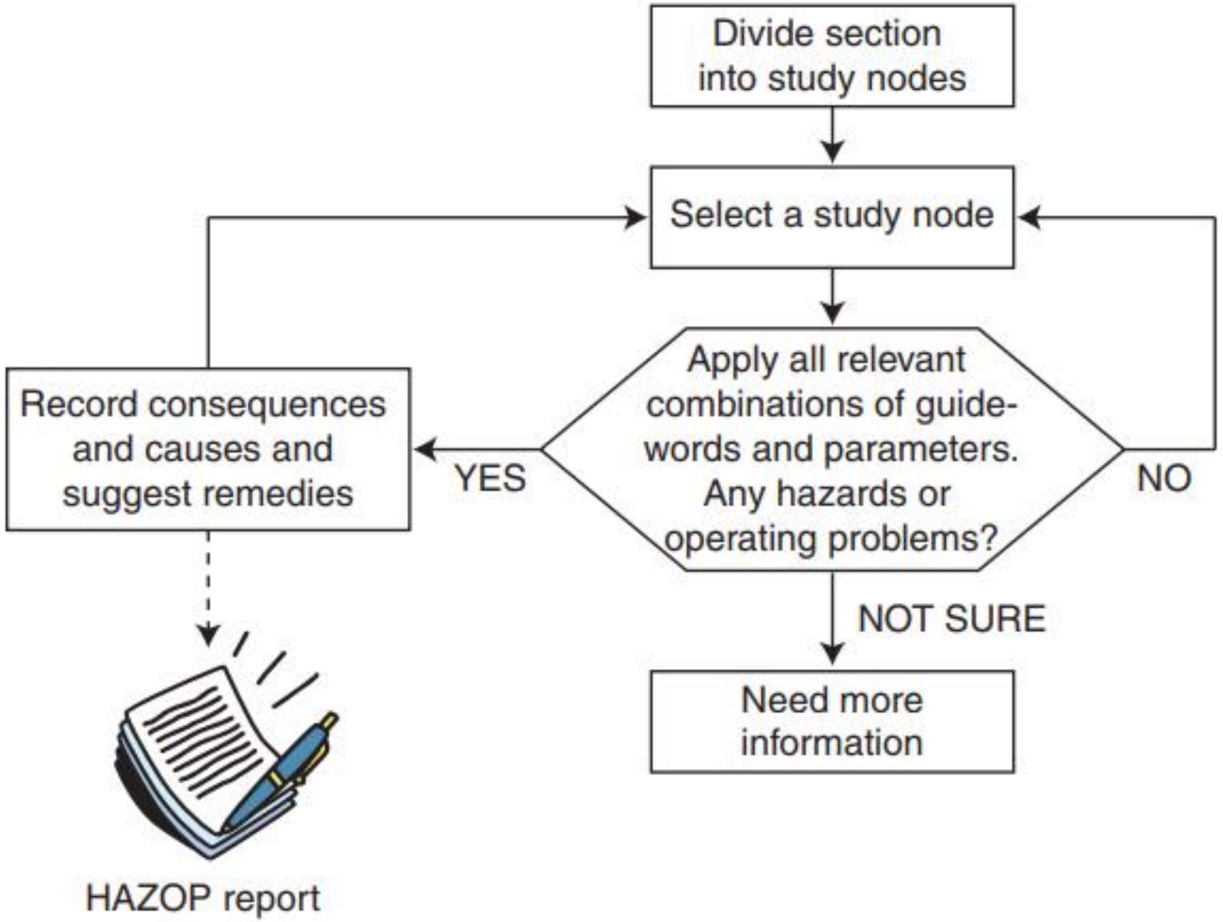
1. Process flow diagrams, along with heat and material balances
2. Process descriptions with interlocks descriptions
3. Piping and instrumentation diagrams (P&IDs)
4. Equipment layout drawings
5. Unit plot plans
6. Material safety data sheets (MSDS) for hazardous chemicals
7. Equipment and instrument datasheets
8. Project control philosophy and cause-and-effect diagrams
9. Provisional operating instructions, and startup and emergency shutdown procedures
10. Utility specifications (as applicable).

HAZOP procedure

1. Divide the system into sections (i.e., reactor, storage)
2. Choose a study *node* (i.e., line, vessel, pump, operating instruction)
3. Describe the *design intent*
4. Select a process *parameter*
5. Apply a *guide-word*
6. Determine cause(s)
7. Evaluate consequences/problems
8. Recommend action: What? When? Who?
9. Record information
10. Repeat procedure (from step 2)

HAZOP procedure

The HAZOP procedure may be illustrated as follows:



Modes of operation

The following modes of plant operation should be considered for each node:

- Normal operation
- Reduced throughput operation
- Routine start-up
- Routine shutdown
- Emergency shutdown
- Commissioning
- Special operating modes

Process HAZOP worksheet

<table>
<tr><td colspan="7">Study title:</td><td colspan="3">Page: of</td></tr>
<tr><td colspan="3">Drawing no.:</td><td colspan="4">Rev no.:</td><td colspan="3">Date:</td></tr>
<tr><td colspan="7">HAZOP team:</td><td colspan="3">Meeting date:</td></tr>
<tr><td colspan="10">Part considered:</td></tr>
<tr><td colspan="3">Design intent:</td><td colspan="7">Material: Activity:
Source: Destination:</td></tr>
<tr><td>No.</td><td>Guide-word</td><td>Element</td><td>Deviation</td><td>Possible causes</td><td>Conse-quences</td><td>Safeguards</td><td>Comments</td><td>Actions required</td><td>Action allocated to</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Worksheet entries

- **Node**
  A node is a specific location in the process in which (the deviations of) the design/process intent are evaluated. Examples might be: separators, heat exchangers, scrubbers, pumps, compressors, and interconnecting pipes with equipment.
- **Design Intent**
  The design intent is a description of how the process is expected to behave at the node; this is qualitatively described as an activity (e.g., feed, reaction, sedimentation) and/or quantitatively in the process parameters, like temperature, flow rate, pressure, composition, etc.
- **Deviation**
  A deviation is a way in which the process conditions may depart from their design/process intent.

Worksheet entries - (2)

- **Parameter**
  The relevant parameter for the condition(s) of the process (e.g. pressure, temperature, composition).
- **Guideword**
  A short word to create the imagination of a *deviation* of the design/process intent. The most commonly used set of *guide-words* is: no, more, less, as well as, part of, other than, and reverse. In addition, guidewords like too early, too late, instead of, are used; the latter mainly for batch-like processes. The *guidewords* are applied, in turn, to all the *parameters*, in order to identify unexpected and yet credible *deviations* from the design/process intent.

Guide-word + Parameter → Deviation

Worksheet entries - (3)

- **Cause**
  The reason(s) why the *deviation* could occur. Several *causes* may be identified for one *deviation*. It is often recommended to start with the causes that may result in the worst possible consequence.

- **Consequence**
  The results of the *deviation*, in case it occurs. *Consequences* may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product. Several *consequences* may follow from one cause and, in turn, one *consequence* can have several *causes*

Worksheet entries - (4)

- **Safeguard**
  Facilities that help to reduce the occurrence frequency of the *deviation* or to mitigate its *consequences*. There are, in principle, five types of *safeguards* that:

  1. Identify the deviation (e.g., detectors and alarms, and human operator detection)
  2. Compensate for the deviation (e.g., an automatic control system that reduces the feed to a vessel in case of overfilling it. These are usually an integrated part of the process control)
  3. Prevent the deviation from occurring (e.g., an inert gas blancket in storages of flammable substances)
  4. Prevent further escalation of the *deviation* (e.g., by (total) trip of the activity. These facilities are often interlocked with several units in the process, often controlled by computers)
  5. Relieve the process from the hazardous deviation (e.g., pressure safety valves (PSV) and vent systems)

Process parameters

Process parameters may generally be classified into the following groups:

- Physical parameters related to input medium properties
- Physical parameters related to input medium conditions
- Physical parameters related to system dynamics
- Non-physical tangible parameters related to batch type processes
- Parameters related to system operations

  These parameters are not necessarily used in conjunction with guide-words:

  - Instrumentation
  - Relief
  - Start-up / shutdown
  - Maintenance
  - Safety / contingency
  - Sampling

Examples of process parameters

Flow	Composition	pH
Pressure	Addition	Sequence
Temperature	Separation	Signal
Mixing	Time	Start/stop
Stirring	Phase	Operate
Transfer	Speed	Maintain
Level	Particle size	Services
Viscosity	Measure	Communication
Reaction	Control	

Guidewords

The basic HAZOP guide-words are:

Guide-word	Meaning	Example
No (not, none)	None of the design intent is achieved	No flow when production is expected
More (more of, higher)	Quantitative increase in a parameter	Higher temperature than designed
Less (lessof, lower)	Quantitative decrease in a parameter	Lower pressure than normal
As well as (more than)	An additional activity occurs	Other valves closed at the same time (logic fault or human error)
Part of	Only some of the design intention is achieved	Only part of the system is shut down
Reverse	Logical opposite of the design intention occurs	Back-flow when the system shuts down
Other than (other)	Complete substitution - another activity takes place	Liquids in the gas piping

Additional guidewords

Guide-word	Meaning
Early / late	The timing is different from the intention
Before / after	The step (or part of it) is effected out of sequence
Faster / slower	The step is done/not done with the right timing
Where else	Applicable for flows, transfer, sources and destinations

Guideword + parameter

Some examples of combinations of guide-words and parameters:

- NO FLOW
  Wrong flow path - blockage - incorrect slip plate - incorrectly fitted return valve - burst pipe - large leak - equipment failure - incorrect pressure differential - isolation in error
- MORE FLOW
  Increase pumping capacity - increased suction pressure - reduced delivery head - greater fluid density - exchanger tube leaks - cross connection of systems - control faults
- MORE TEMPERATURE
  Ambient conditions - failed exchanger tubes - fire situation - cooling water failure - defective control - internal fires

Procedure HAZOP

What is a procedure HAZOP?

A procedure HAZOP is an examination of an existing or planned operation (work) procedure to identify hazards and causes for operational problems, quality problems, and delays.

- Can be applied to all sequences of operations
- Focus on both human errors and failures of technical systems
- Best suited for detailed assessments, but can also be used for coarse preliminary assessments
- Flexible approach with respect to use of guide-words

Procedure

- Breakdown of operation (work) procedure to suitable steps
- Define intention of each step
- Establish boundary conditions

else as
conventional Process HAZOP

- Apply guide-words to intention and boundary conditions for each step.

Guidewords

Guide-word	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (lessof, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution - another activity takes place

Alternative guidewords - (1)

Guide-word	Meaning
Unclear	Procedure written in confusing and ambiguous fashion
Step in wrong place	Procedure will lead to actions out of correct sequence or recovery failure
Wrong action	Procedure action specified is incorrect
Incorrect information	Information being checked prior to action is incorrectly specified
Step omitted	Missin step, or steps too large, requiring too much of the operator
Step unsuccessful	Step likely to be unsuccessful due to demands on operator
Interference effects from others	Procedure-following performance likely to be affected by other personnel carrying out simultaneous tasks (usually when co-located)

Alternative guidewords - (2)

Parameter	Guide-word / deviation
Time	Too early, too late
Sequence	Wrong sequence, omissions, wrong action
Procedure	Not available, not applicable, not followed
Measurement	Instrument failure, observation error
Organization	Unclear responsibilities, not fitted for purpose
Communication	Failed equipment, insufficient/incorrect information
Personnel	Lack of competence, too few, too many
Position	Wrong position, movement exceeding tolerences
Power	Complete loss, partly lost
Weather	Above limitations - causing delayed operation

Reporting and review

Report contents

Summary
1. Introduction
2. System definition and delimitation
3. Documents (on which the analysis is based)
4. Methodology
5. Team members
6. HAZOP results
   - Reporting principles
   - Classification of recordings
   - Main results

Appendix 1: HAZOP work-sheets
Appendix 2: P&IDs (marked)

Review meetings

Review meetings should be arranged to monitor completion of agreed actions that have been recorded. The review meeting should involve the whole HAZOP team. A summary of actions should be noted and classified as:

- Action is complete
- Action is in progress
- Action is incomplete, awaiting further information

Conclusions

HAZOP Results

- Improvement of system or operations
  - Reduced risk and better contingency
  - More efficient operations
- Improvement of procedures
  - Logical order
  - Completeness
- General awareness among involved parties
- Team building

Advantages

- Systematic examination
- Multidisciplinary study
- Utilizes operational experience
- Covers safety as well as operational aspects
- Solutions to the problems identified may be indicated
- Considers operational procedures
- Covers human errors
- Study led by independent person
- Results are recorded

Success factors

- Accuracy of drawings and data used as a basis for the study
- Experience and skills of the HAZOP team leader
- Technical skills and insights of the team
- Ability of the team to use the HAZOP approach as an *aid* to identify deviations, causes, and consequences
- Ability of the team to maintain a sense of proportion, especially when assessing the severity of the potential consequences.

Pitfalls and objections

- Time consuming
- Focusing too much on solutions
- Team members allowed to divert into endless discussions of details
- A few of the team members dominate the discussion
- "This is my design/procedure"
  - Defending a design/procedure
  - HAZOP is not an audit
- "No problem"
- "Wasted time"

November 2016

SPECIAL FOCUS: PLANT SAFETY AND ENVIRONMENT

Useful tips for a successful HAZOP study

The products we use on a daily basis comprise a variety of chemicals.

Kunte, V. A., Sakthivel, S., TATA Consulting Engineers Ltd.

TABLE 1. Sample record sheet of a HAZOP study of a continuous process

				Job No.:	**Team members**		
Client:				**DWG No.:** **Rev. No.:**	**Initials of client's participants:**		**Mtg. No.:** **HZ-01**
Project:				**DWG. title:** **P&ID for:**	**Initials of consultant's participants:**		**Date:** **DD-MM-YYYY**
Sl. No.	**Item/line/ equipment**	**Deviation**	**Causes**	**Consequences**	**Preventive or corrective measures in P&ID (safeguards or instruments)**	**Recommendations**	**Action by**
1	**Node No.: 01**	**Node description: Line from bottom outlet nozzle 'A' of column, C1 to feed inlet nozzle of heat exchanger, E1**					
	3"-P-1101-PPP-lh	High flow	1. Malfunctioning of control valve FV-105 due to stuck open condition.	1a. Level in column C1 will drop.	1a. LAL-101 is provided on bottom of column C1.	1a. NIL	
				1b. Reboiler E2 steam inlet control valve FV-101 will open more.	1b. FT- 102 is provided on steam inlet line of reboiler E2.	1b. FAL-102 and FAH-102 to be provided on steam inlet supply line to reboiler E2.	Consultant
				1c. More feed flow to column C2.	1c. FT-105 is provided on feed inlet to column C2.	1c. FAH-105 to be provided on feed inlet line to column C2.	Consultant

Low/no flow/ low pressure	1.	Malfunctioning of control valve FV-105 due to lesser percentage opening.	1a.	Liquid Level in column C1 will increase.	1a.	LAH-101 is provided on bottom of column C1.	NIL
			1b.	Less feed flow to column C2.	1b.	FAL-105 is provided on feed inlet to column C2.	NIL

High temperature and high pressure	1. Failure of pump P1 A/B.	1. Column C2 can have maximum operating temperature of 130°C.	1. Interlock I-101 on pump P1 A/B is provided.	1. TAH to be provided on column C2.	Consultant
	2. PV-101 malfunctions.	2. Column C1 can see the design temperature of 190°C and design pressure of 10 kg/cm² (g), which are not desirable.	2. PSV-101 and PSV-102 is provided on column C1. TAH-101 is provided on vapor outlet line from column C1.	NIL	
	3. Failure of pump P2 A/B.	3. Process upsets in column C1.	3. Interlock I-102 is provided on pump P2 A/B.	NIL	
	4. Failure of cooling water to E3	4. Process upsets in column C1.	4. TAH-103 is provided on downstream of E3.	NIL	
	5. Steam supply valve to reboiler E2 stuck open.	5. Higher vapor to column C1, leading to process upset.	5. FT-102 is provided on upstream of reboiler E2.	5. FAH-102 to be provided.	Consultant
Low temperature	Steam supply valve to reboiler E2 stuck closed.	Process upsets in column C1.	FT-102 is provided on upstream of reboiler E2.	FAL-102 to be provided.	Consultant

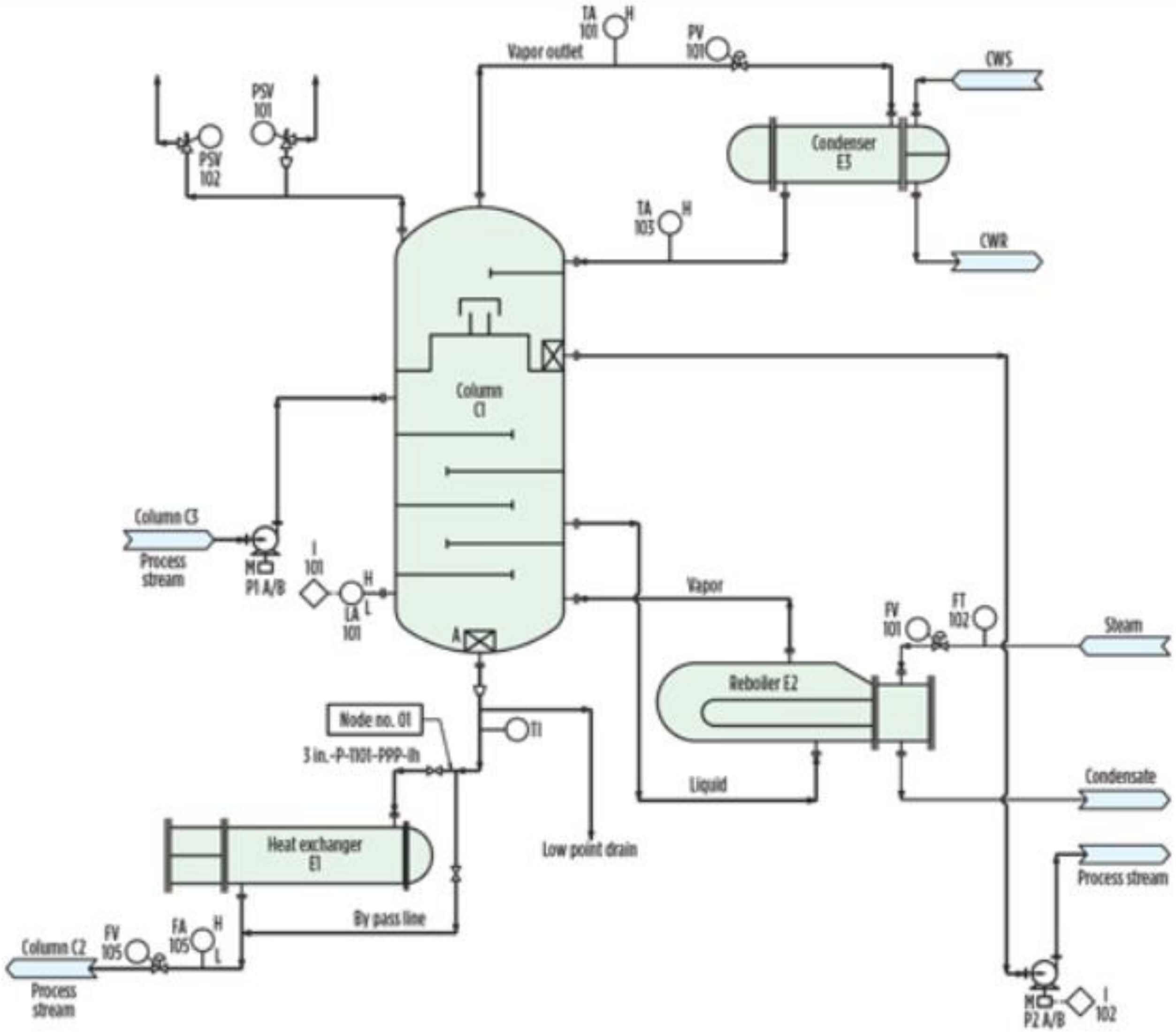


FIG. 1. Schematic diagram of a chemical plant for a HAZOP study of a continuous process.

TABLE 2. Typical guidewords for batch processes

	Guidewords						
Process parameters	**No, not, none**	**Less, low, short**	**Part of**	**More, high**	**As well as, also**	**Reverse**	**Other than**
Flow (H,L)	No flow	Low flow	Wrong concentration	High flow	Contaminates, misdirection	Back flow	Wrong material
Pressure (C,H,L,R,T)	Open to atmosphere	Low pressure	N/A	High pressure	N/A	Vacuum	N/A
Temperature (C,H,L,R,T)	Freezing	Low temperature	N/A	High temperature	N/A	Auto-refrigeration	N/A
Level (C,R,T)	Empty	Low level	Low interface	High level	High Interface	N/A	N/A
Mixing (R,T)	No mixing	Poor mixing	Mixing interruption	Excessive mixing	Foaming	Phase separation	N/A
Reaction (R)	No reaction	Slow reaction	Partial reaction	Runaway reaction	Side reaction	Decomposition	Wrong reaction
Special (C,H, L, P, R, T , X, MX)	Utility failure	Leak	Tube leak	Rupture	Tube repair	N/A	N/A

1. Deviation: Deviation (process parameter + guideword), e.g., poor mixing, excessive mixing, partial reaction, wrong reaction, runaway reaction
2. Other process parameters: (to be used as applicable based on nature of batch process) Composition, viscosity, pH, voltage, current, time sequence, speed, etc.
3. Equipment/item codes: (for which the above deviations are to be considered for a HAZOP study of batch processes and equipment): C = Column, H = Heater, L = Line, P = Pump, R = Reactor, T = Tank/Vessel, X = Heat exchanger, MX = Any mixing equipment, N/A = Not applicable

TABLE 3. Sample record sheet of a HAZOP study of a batch reactor

Item/line/ equipment	Deviation	Causes	Consequences	Preventive or corrective measures in P&ID	Recommendations	Action by
Node No. 1	**Node description : Batch reactor R-101**					
	No mixing	1. Agitator not working	1. Delay in batch operation due to slow/no reaction.	1. Healthiness of the VFD monitored in DCS.	1a. Motor running status to be shown in the next revision of the PID.	Consultant
					1b. RPM monitoring system to be provided.	
		2. Impeller dislocated from the shaft at high RPM.	2. Delay in batch operation due to slow/no reaction.		2. Preventive plant maintenance (PPM) schedule to be developed to check the reliability of the agitator.	Client
	Poor mixing	1. Agitator not working at the desired RPM.	1a. Delay in batch operation due to slow/no reaction.			
			1b. Quality and yield loss of the product.			
	Mixing interruption	Power failure to the agitator.	No major consequences, except delay in batch operation due to interruption.	NIL	NIL	

Reverse mixing	Change in the polarity of the motor after its maintenance.	Desired efficiency of the mixing not achieved leading to delay in batch operation.		Proper direction of the rotation of the agitator to be included in the SOP/PPM.	Client
No reaction	1. Raw material not charged.	1a. Delay in batch operation.	1a. Batch Process Record (BPR) is maintained.	NIL	
		1b. Quality and yield of batch will be affected due to no charging.			
Reactor leak	1. Failure of gaskets of nozzles on the reactor.	1a. Loss of nitrogen to atmosphere/operating area leading to asphyxiation.		1. Online oxygen concentration measurement device to be provided.	Consultant
		1b. Loss of solvent vapor to atmosphere, leading to exposure to the operators.	1b. Smoke/heat detectors provided.		
Jacket leak	1. Due to corrosion. 2. Failure of gaskets of nozzles on the jacket.	1, 2. Failure of utility supply to the reactor	NIL	1, 2. PPM of the jacket to be done at regular intervals	Client

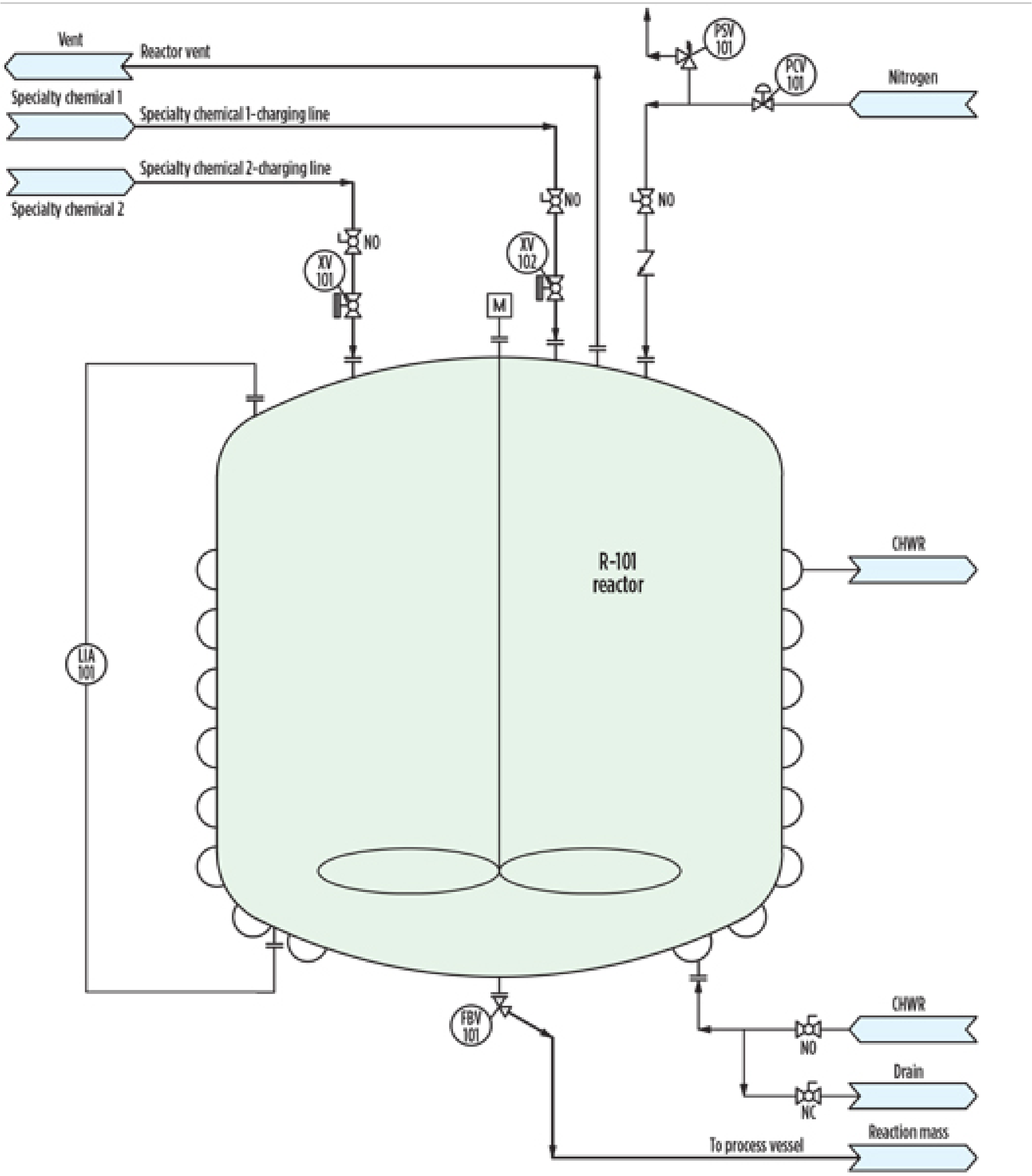


FIG. 2. Schematic diagram of a batch reactor.

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Messages for Manufacturing Personnel

Water, water everywhere…

October 2015

Water is often found in many places in a plant. It is used for cleaning process equipment and pipe, for general building and plant washing, and as a lubricant or seal flush. Water is also a common heat transfer fluid – as cooling water, mixed with salts or glycol for refrigerated cooling, and as steam for heating. Water is a common solvent used in many processes. But water can also be dangerous if it gets into the wrong place. Here are some examples.

- **Water as a reactive chemical:** Water reacts with many materials, and the reaction can cause heat, pressure, or toxic reaction products. The initiating event for the December 1984 Bhopal, India tragedy (Fig. 1), the worst industrial disaster in history, was contamination of a tank of methyl isocyanate with water. The reaction generated heat and pressure, releasing toxic material into the community causing thousands of fatalities and injuries.
- **Water as a reaction catalyst:** Water can catalyze other chemical reactions such as decomposition. For example, contamination of a distillation residue with 1% water reduced its decomposition temperature by 100 ºC. The temperature of steam heating on a pipe containing the contaminated residue was above the reduced decomposition temperature. The residue decomposed and ruptured the pipe (Fig. 2). Fortunately nobody was in the area.
- **Water as a physical explosion hazard:** Water boils at 100 ºC, below the operating temperature of many processes. If water contacts hot material or equipment, it will rapidly boil and generate pressure in a closed or inadequately vented vessel. Water can explosively increase in volume by 1600-1700 times when it vaporizes to steam at atmospheric conditions. In 1947, a blast furnace in a steel mill Pennsylvania (Fig. 3) was being prepared for replacement of the brick lining. Workers were improperly told to add water to the furnace while it still contained molten iron and other hot materials, in violation of standard operating procedures. The water boiled, and pressure from the steam blew a hole in the bottom of the furnace. Molten metal was released and engulfed nearby workers. There were 11 fatalities.

Fig. 1


Fig. 2


Fig. 3


What can you do?

- Be aware of chemical reaction hazards of water in your plant – as a reactive chemical, and as a catalyst for other reactions. Understand the design features of your plant which protect against hazardous interactions with water.
- Remember the hazard of boiling water from contact with hot (above 100 ºC) equipment or material.
- Always follow standard operating procedures designed to keep water from getting into places in your plant where there may be a dangerous chemical or physical interaction.
- If there are parts of your plant where water is not supposed to be used, never set up a temporary water supply to get water into that area. If there is a real need to use water in an area where it is not normally allowed, there should be a standard operating procedure (SOP) for this special activity. Special precautions may be included in the SOP, and a permit may be required. If this is not the case, make sure that the activity is given a thorough job safety analysis or management of change review, and follow all procedures identified by that review.

Water – common but it can be dangerous!

The Beacon is usually available in Arabic, Afrikaans, Chinese, Czech, Danish, Dutch, English, Filipiono, French, German, Greek, Gujarati, Hebrew, Hindi, Italian, Japanese, Korean, Malay, Marathi, Norwegian, Persian, Polish, Portuguese, Romanian, Russian, Spanish, Swedish, Telugu, Thai, Turkish, and Vietnamese.

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Messages for Manufacturing Personnel

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Can a water pump explode?

August 2013



The answer must be "yes" or we wouldn't have a subject for this *Beacon*! The centrifugal pumps in the pictures are all water pumps which exploded. The explosions did not occur because of any contamination or chemical reaction with something that was not supposed to be in the pump. In fact, explosions like this have happened with very pure water – boiler feed water pumps, condensate pumps, and deionized water pumps.

How did these explosions happen? The pumps were operated for some period of time with <u>both the pump suction and discharge valves closed</u>. Because water could not flow through the pump, all of the energy which normally goes into pumping is instead converted to heat. When water is heated, it expands generating hydrostatic pressure inside the pump. This may be enough pressure to cause the pump to fail – perhaps the seal would fail, or the pump casing might rupture. These explosions may cause significant damage or injuries because of the built-up energy. However, if the water exceeds its boiling point before the pump fails, a more energetic explosion may occur because the released superheated water will rapidly boil and expand (a boiling liquid expanding vapor explosion - BLEVE). The severity and damage will be similar to a steam boiler explosion.

This type of explosion can happen with any fluid if a pump is operated with suction and discharge valves closed. If a non-hazardous fluid like water can result in the damage shown in the pictures, think how much more severe the damage might be if the fluid is flammable - the released material could catch fire. If the fluid is toxic or corrosive, people near the pump could be severely injured by the released material.

What can you do?

➔ Before starting any pump, check that all valves are in the correct position. Be sure that the valves in the intended flow path are open, and other valves, such as drains and vents, are closed.

➔ If you are starting a pump from a remote location such as a control room, be sure that the pump is ready for operation. If you are not sure, go to the pump and check it, or have somebody else check it.

➔ Make sure that key steps important for safe operation of pumps, including all valve positions, are included in your plant operating procedures and checklists.

➔ Some pumps are started automatically – for example by a process control computer or a level instrument to automatically empty a tank when it is filled. Make sure that all of the valves are in the correct positions when putting these pumps into automatic operation, for example, after maintenance.

➔ Some pumps have instrumentation installed to prevent running while blocked in – for example, low flow, high temperature, or high pressure interlocks. Be sure that these safety systems are properly maintained and tested.

See the October 2002 *Process Safety Beacon* for a similar incident.

Don't let your pumps run while blocked in!

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Air Power!

September 2013

Air is always all around us, and the oxygen it contains is necessary for life. But, ***compressed air*** (or any other compressed gas) contains a lot of energy and can cause major damage in case of a vessel or pipe failure. The pictures show the consequences of three explosions resulting from failure during pneumatic pressure testing of pipes and vessels.

1. A flange failed while pressure testing a 36 inch (~1 meter) diameter pipe at about 1,800 psig (12.41 MPa, or ~125 bar) compressed air pressure. One person was killed, 15 injured, and there was significant damage to the equipment.
2. Pipes connected to a tank were pressure tested using compressed air. The tank was isolated from the pipes by closing valves, and there was no blind or other positive isolation. A valve leaked allowing air to pressurize the tank. It took off like a rocket and landed on top of the process rack! (See the October 2007 *Beacon*)
3. In this incident, the compressed gas was nitrogen (not air), but the consequences of the explosion are similar. A pipeline failed during the compressed nitrogen pressure test, killing one worker and seriously injuring three others.

What can you do?

➔ Whenever possible, pressure test equipment using water (hydrostatic test) or another non-hazardous liquid. Water is a non-compressible fluid, and water at a given pressure contains a lot less energy than a compressed gas such as air. Think about the difference in the sound of bursting a balloon filled with water compared to one filled with air. The air filled balloon "pops", but the water filled balloon does not make much noise.

➔ Before you start a pressure test, think about the consequences if a failure occurs. Take precautions so that people are not at risk during the test. Remember that it is a test – what happens if the equipment fails the test?

➔ Do not rely on valves only to isolate equipment being tested from other equipment that is not strong enough to withstand the test pressure. Provide positive isolation with blinds or physical disconnection of piping.

➔ Use an approved written pressure testing procedure, and follow it rigorously.

➔ Post warning signs and restrict access to places where pressure testing is being done.

➔ Make sure that people who are not directly involved in the test are not allowed in the area for any reason.

➔ If you must use pressurized gas for a test, do a thorough safety review before conducting the test.

Think about what could happen if your equipment fails to pass the pressure test!

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Recent nitrogen fatalities are a vivid reminder

April 2021

Figure 1. Location of 6 fatalities from a nitrogen leak
Source: Insurance Journal

Figure 2. Warning signs for liquid nitrogen hazards

A recent event in Gainesville, Georgia, US, involved a significant leak of liquid nitrogen. A poultry processing plant used liquid nitrogen to quickly freeze chicken products. This freezing system had only been in operation for 4-6 weeks before the event. Six workers died and 12 others were taken to a hospital. 130 people had to be evacuated. A maintenance manager shut off an external isolation valve, stopping the flow of liquid nitrogen to the process and likely preventing further exposures. While the causes are still under investigation, it serves as a reminder for us to understand the hazards of nitrogen and use extreme caution when working in or around nitrogen consuming operations.

Many other oxygen deficiency incidents have occurred due to nitrogen leaks or purging. Entering a confined space with an oxygen deficient atmosphere without testing or a proper breathing apparatus is one of the most frequent causes of asphyxiations.

Did You Know?

- In the US, nitrogen asphyxiation hazards in industry resulted in 80 deaths from 1992 to 2002. These incidents occurred in a variety of facilities, including industrial plants, laboratories, and medical facilities; almost half involved contractors. More recently, fourteen workers in the US, died from asphyxiation linked to nitrogen accidents from 2012 to 2020, according to AP news agency.
- Nitrogen is sometimes called "the silent killer" because it is odorless, colorless, tasteless and gives no warning. People in a nitrogen enriched environment (low in oxygen) simply lose consciousness before realizing they are in danger. Low oxygen can be detected only with the correct gas detectors..
- In addition to its asphyxiation hazards, liquid nitrogen is extremely cold and contact can quickly cause severe frostbite burns.
- Many nitrogen-related fatalities occur when others rush to rescue a worker in an oxygen deficient atmosphere. No one should enter a potentially oxygen deficient space without proper permits, preparation, and breathing apparatus.

What Can You Do?

- Read the SDS for nitrogen to review its hazards and precautions.
- Review the US Chemical Safety Board's guidance on nitrogen. Follow the link below for both the Hazards of Nitrogen Asphyxiation bulletin (No. 2003-10-B June 2003) and a PowerPoint presentation on nitrogen hazards.
  - (https://www.csb.gov/hazards-of-nitrogen-asphyxiation/)
- Watch the CSB safety video on the Valero Refinery Asphyxiation incident.
  - (https://www.csb.gov/valero-refinery-asphyxiation-incident/)
- Be aware where nitrogen is being used in your area and look for potential release points such as open pipes, relief discharges or other possible leak points.

Past Beacons – April 2004, December 2006, August 2007, April 2015, November 2017, and June 2018 [Beacon Archive: https://www.aiche.org/ccps/resources/process-safety-beacon/archives]

Other references: EIGA: https://www.eiga.eu/publications/safety-leaflets/sl-0117-dangers-of-asphyxiation/
CGA: https://www.cganet.com/liquid-nitrogen-safety/

Nitrogen is often a safeguard, but it also has serious hazards.

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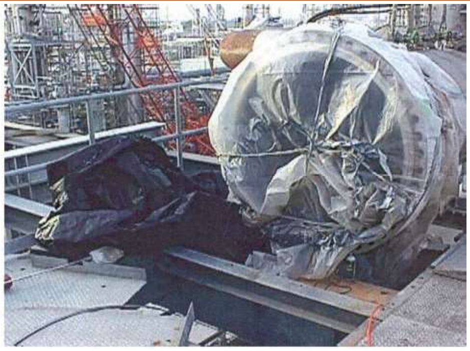
Nitrogen – Hazard and Safeguard!

June 2012



This Beacon is not focused on a single incident, but on incidents that continue to occur across industry – nitrogen asphyxiation. A June 2003 United States Chemical Safety Board (CSB) bulletin reported nitrogen asphyxiation incidents in US industry resulting in 80 deaths from 1992 to 2002. These incidents occurred in many different workplaces – industrial **plants**, laboratories, and medical facilities. Many of the incidents involved contractors. The pictures are some examples of the kind of places where a dangerous concentration of nitrogen could accumulate, taken from CSB reports.

While nitrogen itself is not toxic, a high nitrogen concentration in the air you breathe will starve your body of the oxygen needed to sustain life. 78% of the air we normally breathe is nitrogen, and oxygen makes up most of the rest. People cannot function well when the nitrogen concentration is more than 84% (16% oxygen). Your judgment may be impaired and you may not recognize that you are in danger! At 94% nitrogen concentration, death is likely in a few breaths.

On the positive side, nitrogen is an inert gas which reduces fire potential by eliminating the oxygen required for a fire. For this reason nitrogen is commonly used to purge piping and equipment used in flammable material service.

Effects of Oxygen Deficiency on the Human Body *

% Oxygen	Effect
20.9	Normal
19.5	Legal minimum concentration for humans (US OSHA)
15–19.5	Decreased ability to work; early symptoms in persons with heart, lung, or circulatory problems
12–15	Increased pulse rate and respiration, impaired judgment
10–12	Further increase in pulse and respiration, giddiness, poor judgment, blue lips
8–10	Mental failure, nausea, fainting, vomiting, unconsciousness
6–8	8 minutes - 100% fatalities; 6 minutes - 50% fatalities
Less than 6	Coma in 40 seconds, convulsions, breathing stops, death

* P. Yanisko and D.Kroll, "Use Nitrogen Safely", *Chemical Engineering Progress*, March 2012, p. 44-48..

What can you do?

- Know where nitrogen gas is vented. It should be outdoors or to a system designed to safely receive nitrogen.
- Where nitrogen is used, consider monitoring the oxygen concentration in the area to ensure it does not drop below safe levels.
- Know where nitrogen is used in your plant, and make sure that all nitrogen pipes are clearly labeled.
- Inspect hoses used in nitrogen service as you would any hose containing toxic gas. Do not use a hose found to be leaking.
- Never assume the oxygen concentration in a vessel or any other confined space is acceptable. Always measure it before working near a vessel opening or inside any confined space.
- Make sure that the ventilation systems in your plant are working correctly. They are not just for comfort – they also remove potentially hazardous air contaminants.
- Recognize that a confined space can be created by temporary obstructions such as plastic or canvas tarps or other temporary weather protection enclosures.
- Read the US Chemical Safety Board bulletin on nitrogen asphyxiation, available from www.csb.gov.

Be aware of nitrogen and other inert gas hazards!

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Incident Investigation of a Steam Pipe Failure

June 2017


Figure 1: Damage

In November 1998 a 12 in. (30.5 cm), 600 psig (~ 41 bar[g]) steam pipe in a large chemical plant failed catastrophically. A 36 in. (~ 1 m) long section of pipe just upstream of a decommissioned venturi flow meter suddenly ruptured causing major damage in the area (Fig. 1). Steam supply throughout the plant was lost, the steam generation equipment shut down, and there was no production in most of the plant for more than 5 days. Fortunately there were no injuries or fatalities.

An investigation team was immediately formed to understand the cause of the failure of the 30 year old pipe (Fig. 2). There was concern about other steam piping which might be in danger of a similar failure. The team consisted of utility operating and management personnel, materials and mechanical engineers (piping, reliability, and failure analysis experts), and chemical engineers. The initial suspected cause was erosion of the pipe wall immediately upstream of the venturi caused by poor quality (wet) steam, resulting in thinning of the pipe wall. Observed lines on the pipe (Fig. 3) were believed to be created by erosion.


Figure 2: Failed pipe

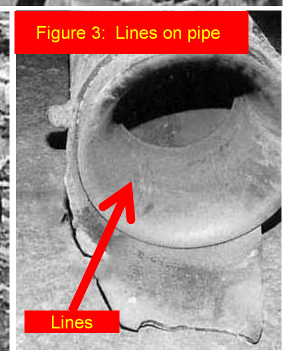

Figure 3: Lines on pipe

In the course of the investigation it was determined that the pipe which failed had been designed to have a slight taper (about 10º) to smooth flow to the venturi. This taper was produced by boring a thicker piece of pipe to the designed profile. The investigation team asked an experienced machinist to inspect the failed pipe. The machinist immediately recognized that the lines were not signs of erosion, but actually tool marks from a boring tool. When the pipe was bored, the tool had not been inserted properly, but off-center. This resulted in the pipe being only about 25% of the intended thickness at the top, and consequently weakened.

Did you know?

There is a reason for including a team of people with different expertise in an incident investigation, or any other process safety management activity (process hazard analysis, management of change, pre-startup safety review, etc.). Everybody involved has a unique expertise to bring to the discussion, based on their education, training, and most importantly, their work experience. In this incident, the engineers and other experts did not recognize the machine tool marks on the failed pipe, and yet it was immediately obvious to the expert, experienced machinist. His knowledge completely changed the conclusions of the investigation, and was essential for understanding the cause of the incident.

Reference: Lodal, P. N., *Process Safety Progress* **19** (3), pp. 154-159 (2000).

What can you do?

- If you are asked to participate in an incident investigation, be a full participant and share your knowledge and expertise with the rest of the team. Your experience in operating or maintaining the plant is important for understanding the incident. Share that knowledge and ask questions. If something in the discussion doesn't sound consistent with your experience, make sure that it is resolved to your satisfaction.
- You may be involved in other process safety management activities as an operations or maintenance representative – for example, management of change, process hazard analysis, writing procedures, developing training material, pre-startup safety reviews, and others. Be an active participant in these activities, and share your knowledge with other participants.

Everybody has something to contribute when investigating an incident!

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Messages for Manufacturing Personnel
November 2002

WHAT HAS YOUR STEAM UP

The Incident:
At first glance, this appears to be a traffic incident – but take a closer look! You are looking at a process safety event. The photos graphically explain what happens when HOT asphalt is added into a trailer that has been recently cleaned with water. Unfortunately, the excess water is not removed from the trailer before adding the asphalt - the water rapidly turns to steam and expands in volume about 1600 times. The result - significant damage. In this case it's a tanker, but it could just as easily have happened to a vessel or piping system. No injuries occurred.

Common Causes of failures like this:
This type of event has happened **MANY** times, often involving heat transfer fluids, mineral oils or other "heavy" organic materials (like the asphalt above). The event begins when a HOT material is added to a vessel or piping which contains materials with a boiling point under the temperature of the hot material. In general, the larger the difference between the temperature of the hot material and the boiling point of the lower boiling material, the more significant the damage. As heat is transferred from the hotter material, vaporization of the lower boiling material occurs and the pressure that results can cause lots of damage!

What Can I do?

- ☑ During **ANY** material transfer, if the liquid being transferred is hotter than 212F/100C – take steps to make certain there is no water in the downstream equipment.
- ☑ Water removal is often difficult in complex piping systems: Low point drains **MUST** be opened, piping must be carefully examined for "traps" and flanges may need to be opened in **MANY** locations.
- ☑ Shipping containers are frequently cleaned with water; any shipping container must be assumed to contain water unless steps have been taken to remove it.
- ☑ Proceed slowly when starting up processes following shutdowns, especially with fluids that are very hot.

HOT liquids have many hazards! Don't forget they can lead to significant pressure buildup if added to vessels containing water or other materials with boiling points lower than the temperature of the hot fluid.

Contact us at ccps@aiche.org or 212-591-7319. http://www.aiche.org/ccps/safetybeacon.htm

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Messages for Manufacturing Personnel

February 2002

A little “nothing” can really be deflating!

Here’s what happened……

When steam cleaning the interior of a railcar most of the air was displaced. When work was stopped at the end of the day all valves were closed. As the car cooled, the steam condensed, creating a vacuum, causing the railcar to collapse

During painting, a tank’s vacuum relief valve was covered with plastic to prevent potential contamination of the contents. When liquid was pumped out the plastic covering prevented air/nitrogen from replacing the liquid volume. A vacuum developed leading to the partial collapse of the tank.

VACUUM is a powerful force!

COMMON causes of vacuum damage to tanks include:

- The vessel has insufficient strength to withstand a vacuum; a vessel with a 50 psig (or higher) ASME pressure rating is frequently capable of withstanding a full vacuum;
- vacuum is created when liquid is transferred from a vessel or when hot vapor condenses, neither of which is replaced by air/nitrogen or other non-condensable material, and
- a vacuum relief system is not present or is not functioning properly.

Things to consider to prevent equipment damage from vacuum:

- install a system to provide vacuum relief. As one of the pictures graphically demonstrates, railcars and trucks MAY NOT have this equipment. These devices will allow air to enter the vessel and prevent vacuum formation.
- if installed, vacuum relief devices must be inspected and tested on a regular basis. They are just as critical as pressure relief devices.
- understand which vessels in your department are not rated for full vacuum. These are the vessels vulnerable to vacuum related incidents,
- demonstrate caution whenever liquids are transferred or vapors are condensed because of shutdown, maintenance, cleaning, etc..
- be sure that the addition of air, nitrogen, or other vacuum breaking materials are not impeded.

WHENEVER vacuum relief systems are removed, covered, modified, etc., special precautions are needed to prevent an incident!

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Vacuum trucks can catch fire AND explode!

March 2020

Typical vacuum truck

Photo of the vacuum truck incident (Santa Clara Wastewater Co. explosion)

At a wastewater facility in Santa Paula (Southern California), on November 18, 2014, a vacuum truck explosion sprayed hazardous material over the site and sent dozens, including three firefighters, to hospital.

Sodium chlorite, an oxidizing agent, was identified in the months following the disaster. Apparently, the chemical was being using as a water treatment agent for the first time. It was vacuumed into the truck, which was used for disposal of other materials. The combined substances interacted, causing an explosion that blew off the back of the truck and spread the contents across the area. Upon release, the mixture dried and started to burn. Explosions spread the fire to surrounding containers, sending billowing black smoke into the sky and forcing police to shut down several roads. Residents within one mile were subject to mandatory evacuations, and those within three miles were ordered to shelter in place.

Did you know?

- Vacuum truck fires/explosions can occur due to incompatible materials combined in the truck.
- Another cause is presence of flammable liquids:
  - Vacuum trucks operate at lower pressure, which can cause low-boiling material to vaporize. These vapors can exit through the truck's vent and could ignite.
  - Vacuum trucks can draw in liquid and some air, which can create a flammable mixture in the vapor space of the truck and generate static electricity due to the mixing of liquids and air.
  - The mixing and turbulence inside a vacuum truck are ideal for static generation.

What can you do?

- Many companies use permit systems to safely manage vacuum truck operations. If you are working near a vacuum truck, make sure all aspects on the permit are completed correctly.
- Vacuum trucks collect materials from many sources. Before starting, make sure your material and what is in the truck are compatible. If you are not sure, stop and ask.
- Verify all vehicles being loaded or unloaded are grounded and bonded – including vacuum trucks.
- Vacuum trucks can be used anywhere. If the vent discharge can contain flammable vapors, make sure it will not contact any ignition sources.

Vacuum trucks are useful systems that require special attention

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February 2007

Vacuum Hazards - Collapsed Tanks

The tank on the left collapsed because material was pumped out after somebody had covered the tank vent to atmosphere with a sheet of plastic. Who would ever think that a thin sheet of plastic would be stronger than a large storage tank? But, large storage tanks are designed to withstand only a small amount of ***internal*** pressure, not vacuum (external pressure on the tank wall). It is possible to collapse a large tank with a small amount of vacuum, and there are many reports of tanks being collapsed by something as simple as pumping material out while the tank vent is closed or rapid cooling of the tank vapor space from a thunder storm with a closed or blocked tank vent. The tank in the photograph on the right below collapsed because the tank vent was plugged with wax. The middle photograph shows a tank vent which has been blocked by a nest of bees! The February 2002 Beacon shows more examples of vessels collapsed by vacuum.

Did you know?

- Engineers calculated that the total force from atmospheric pressure on each panel of the storage tank in the left photograph was about 60,000 lbs.
- The same calculation revealed that the total force on the plastic sheet covering the small tank vent was only about 165 lbs. Obviously this force was not enough to break the plastic, and the tank collapsed.
- Many containers can withstand much more internal pressure than external pressure – for example a soda can is quite strong with respect to internal pressure, but it is very easy to crush an empty can.

What can you do?

- Recognize that vents can be easily blocked by well intended people. They often put plastic bags over tank vents or other openings during maintenance or shutdowns to keep rain out of the tank, or to prevent debris from entering the tank. If you do this, make sure that you keep a list of all such covers and remove them before startup.
- Never cover or block the atmospheric vent of an operating tank.
- Inspect tank vents routinely for plugging when in fouling service.

Vacuum – it is stronger than you think!

The Beacon is usually available in Arabic, Chinese, Dutch, English, French, German, Gujarati, Hebrew, Hindi, Italian, Japanese, Korean, Portuguese, Spanish, Swedish, and Thai.

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Vacuum can put a dent in your process!

February 2024

Figure 1: Inlet duct to a dryer collapsed under vacuum

Figure 2: Railcar collapsed after steam out

What happened? A process containing flammable materials was operating under vacuum. Suddenly, the vent line collapsed. Equipment can collapse when the internal pressure caused by the vacuum is lower than the equipment's vacuum rating. Vacuum can be created inside equipment by:

- Exposing equipment to a strong vacuum source, such as an eductor or vacuum pump, without adding a gas to control the pressure (See Figure 1)
- Draining a tank without properly venting the headspace.
- Cooling a tank without venting it – this can even occur if a vessel vent is blocked and the ambient temperature decreases like a sudden rain.
- Steaming a vessel without venting it – the water vapor can condense and create a vacuum inside the equipment (see Figure 2)

Why is creating vacuum a problem? Beyond the potential for vessel collapse, vacuum can cause other potentially unsafe conditions. Air can be drawn into the equipment; if the process contains flammable materials, an ignition or explosion could occur. Vacuum could also cause materials in the process to boil unexpectedly or foam. There is also a risk of backflow in equipment, since materials tend to flow toward lower pressure points in the process.

Did You Know?

- When a process runs at less than atmospheric pressure (vacuum), the process contains less air than at atmospheric pressure. If it is operating near full vacuum, (0 psia or 0 mm Hg), there is little air in the process.
- Equipment rated for internal pressure may not be rated for vacuum. Pressure and vacuum ratings for equipment can be found on the equipment tag or the equipment data sheet.
- Vacuum control systems reduce the pressure by opening valves to a vacuum source. The pressure can be raised by adding a gas (usually inert) into the process to raise the pressure.
- For boiling processes, lower pressure allows most materials to boil at a lower temperature. This is often how high boiling materials are separated.

What Can You Do?

- Understand how the vacuum systems work for your processes – both how the vacuum is created and how the pressure is controlled.
- Recognize that loss of vacuum in a flammable system could mean that air got into the process. Follow your unit's procedures to manage the upset.
- Do not block the vent of a tank without providing a venting path, such as a vacuum relief device.
- Don't steam out equipment or pump material out of a tank or vessel without a venting path or other means of protection from vacuum.
- During hazard reviews, discuss all the possible causes of vacuum. Some consequences may be more than a quality problem; they could be an unsafe situation.

Do not let vacuum collapse your equipment!

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Messages for Manufacturing Personnel

June 2002

DON'T GET YOUR PIPES IN A TWIST

This picture was just too good to pass up! We do not know where it came from. It may show, unlike our previous photos, something that does not exist in real life. If someone would like to say, "yep, that's my location", please let us know! We'll send you a t-shirt (or something!) for your trouble.

The next time you hear these statements, think of this picture!

- "**We need to be able to pump everything to everywhere!**" Life is complicated – and sometimes our desire for flexibility creates REALLY complex facilities.
- "**Line up tank 146, through the new bypass line, to the old stainless heat exchanger and then to the south tank!**" We need to be clear and precise when we communicate with each other.
- **"No need to look at the operating instructions, I remember the valving for that setup!"** In many cases, we don't refer to these documents as often as we should.
- "**Every one of those lines has a management of change form!**" Management of change is a powerful tool, but looking at this piping – one line at a time, by itself – seems to miss something. Management of change must also deal with how the change fits into the existing facility.
- "**Harry, you need to use a 2" x 12" plank to get to that valve!**" Operability is a key parameter for new equipment. What you see here would seem to be difficult to operate (maybe an understatement?)! Being able to reach equipment is an important feature.
- "**We never dismantle piping – might need it someday!**" Removing any equipment item is difficult, but when it becomes a hindrance to operability someone needs to make the right decision.
- "**Nancy, when you break the flange to replace that gasket, lets get a bucket underneath to catch any drips!**" Maintainability is another key parameter for new equipment.
- "**We pride ourselves on being in complete compliance with all regulations!**" And, the facility depicted above may indeed be in compliance. But, sometimes we need to stand back and ask the simple question – is this facility easy to run safely?

Operating a plant is a complex task requiring a number of different skills. Doing them all, correctly, every time, is essential!

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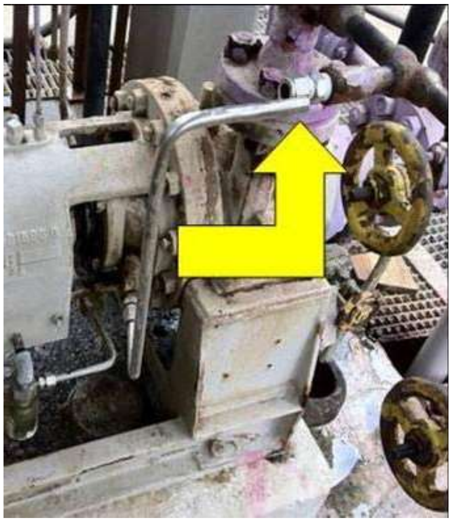
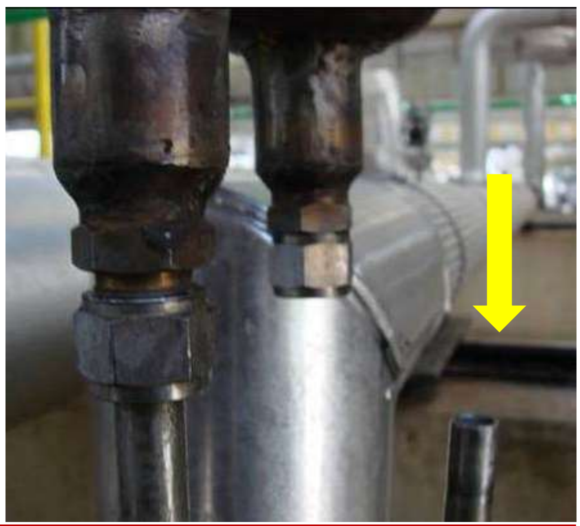
Mechanical Integrity of Tubing

May 2012



Proper installation, maintenance, and inspection of metal tubing is important in preventing fires and toxic material releases in process plants. Don't forget about tubing just because it is usually small. Even a small leak can cause a fire which can grow much larger, and small releases of toxic materials can be dangerous. Here are some reported incidents.

- A ½-inch stainless steel tube between a glycol pump and a process vessel failed at a fitting near the process vessel. The resulting leak sprayed onto a reboiler and ignited causing significant equipment damage. The tubing failure was concluded to be the result of vibration caused by the glycol pump.
- A 1-inch stainless steel supply tube to a gas scrubber failed at a nut and ferrule compression fitting. The resulting gas leak ignited but self-extinguished without major damage. The exact cause of the tubing failure was not determined, but pressure charts indicated that there had been an over-pressure excursion before the incident. Also, the tubing could have been damaged or weakened during storms in the previous hurricane season.
- During startup of an LNG plant, a gas leak from ½-inch tubing for a pump seal was detected. Repairs were done by a technician who had not been properly trained. When the plant was re-started, the tubing failed completely causing an LNG leak and fire.



Note: The pictures are examples of tubing failures and are not from the incidents described.

What can you do?

- ➔ Review your plant procedures for installation, inspection, and maintenance of tubing.
- ➔ Remember that tubing may not be as durable as pipe and may be more easily damaged. Avoid impacts to tubing and tubing connections.
- ➔ Report any damaged or leaking tubing which you observe in your plant and follow up to ensure it is repaired.
- ➔ Be aware that the installation and repair of tubing must be done by a qualified and properly trained technician.
- ➔ Use the proper tools and procedures, including for bending and crimping, for installation and maintenance of tubing.
- ➔ Use the correct components – tubing, ferrules, nuts, and fittings. Do not mix components from different manufacturers.
- ➔ Ask the supplier of your tubing and tubing fittings to provide information on proper installation and maintenance of their product.

Don't forget tubing in your mechanical integrity programs!

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Messages for Manufacturing Personnel

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On the safe side.

Plugged line & equipment – More than a nuisance

September 2019

Fig. 1 Plugged vent line

The CSB investigated an incident where a process upset plugged the vent (Fig. 1) and the relief device on the waste surge tank. When the maintenance personnel came to open the surge tank to clean-out the surge tank, residual pressure blew the heavy cover off (Fig. 2), killing all 3 of them. Why did this happen?

Why did the maintenance people open the tank while it was under pressure? During the start-up the process had diverted off-spec product to the surge tank that released gas, and fouling of the vent had increased pressure in the tank. The pressure indicator (gauge) was also plugged and did not register any pressure.

Fig. 2 Blown-off lid

Did you know?

- Plugged lines and equipment are a nuisance; clearing them safely can be a lot of messy work. Plugged lines and equipment can be connected with and indicate another major issue – blocked key instrumentation or relief devices.
- Many things can cause plugging, higher melting materials, solids in the process stream or corrosion products. Unplugging equipment needs proper isolation before starting any line/equipment opening. (LOTO).
- A procedure should exist or be created to list the corrects steps and methods before starting clearing the lines.

What can you do?

- Plugged lines and equipment are indicators of other problems – a process upset, excess corrosion, etc. Report plugging even if a minor process problem occurs.
- Frequently plugged lines or equipment need to be investigated to avoid upsets and problems with clearing them.
- Before clearing lines or equipment stop to review how the work will proceed and what other hazards could be present creating exposure during clearing.

When equipment plugs, it may be a warning that other equipment is plugged too

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Process Safety Beacon
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Explosion of a tank containing "mostly water"

August 2021

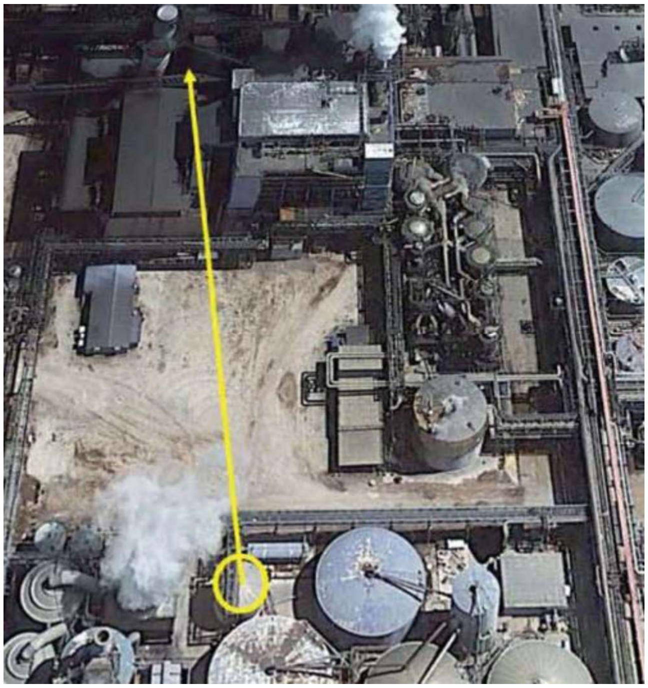

Figure 1. Yellow circle shows the pre-incident location of the condensate tank. The yellow line indicates the tank's path following the explosion. (Photograph from CSB Report Packaging Corporation of America (2017-03-I-LA-1)

An incident in DeRidder, Louisiana, on February 8, 2017, was investigated and reported by the US Chemical Safety Board (CSB). The explosion occurred in a condensate tank (mostly water but containing some organic material) which led to an unanticipated flammable atmosphere.

According to the CSB report, the condensate tank failed at its base and traveled approximately 375 feet, over a six-story building before landing on process equipment. There were three fatalities from the explosion, and seven people were injured.

The source of ignition was probably Hot Work that was performed near the tank. The organic material in the tank was turpentine, a solvent obtained from resin, contained in wood, during paper manufacturing. It consists of several hydrocarbons and is different from mineral turpentine, also called white spirit.

Did You Know?

- Combustible material, a fuel, can form an explosive atmosphere when enough of it is dispersed in air. For liquids, this dispersion is usually caused by evaporation.
- This explosive atmosphere contains the fuel in a certain concentration range, the explosive (or flammable) range. Below this there is not enough fuel, above it there is not enough oxygen in the mixture. 20 g/m³, 4 tablespoons evaporated in 100 cubic feet, can be sufficient.
- Liquids that are volatile enough to create an explosive atmosphere at "normal" temperatures are called flammable liquids and are labeled accordingly. Different systems exist to define what these "normal" temperatures are.
- If the temperature of a liquid is high, it forms an explosive atmosphere even if it is not labeled flammable!
- In processes that involve water and organic liquids, these liquids usually have lower density than water and can float on top of it.
- In bulk tanks, the layer of flammable liquid can vaporize to create an explosive atmosphere in the tank's vapor space (Figure 1).
- Tanks are often protected from over pressure or vacuum with a "breather vent". These vents can allow air to enter the tank when draining it or vapor to escape when filling.
- Some companies inert bulk tanks containing flammable liquids to prevent ignition of the contents.

What Can You Do?

- Know the properties of the materials used in your area. Pay special attention to tanks that may have two or more phases (layers) in them.
- Wastewater tanks can have a flammable phase that accumulates over time. These tanks may need to be treated as if they contained a flammable material.
- Inspect the inerting systems on your tanks and verify they are operating properly.
- During Hot Work around tanks with flammable or combustible contents, be vigilant and follow the company's Hot Work procedure (ref. Aug-20 Beacon).

A small quantity of flammable liquid is no small hazard!

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The agitator stopped! Now what??

November 2023

Figure 1. Resin building after the internal explosion (Source: CSB report No. 2021-04-I-OH)

The incident occurred when the reaction in a vessel was nearly complete. While the operator was not near the reactor, the agitator shut down. A few minutes later, the operator began cooling the kettle's contents; the agitator should have been running, but it remained stopped.

The operator added solvent into the top of the kettle. The batch temperature was about 430°F (221°C), and the solvent was at approximately 70°F (21°C). The operator noticed that the temperature was not dropping and looked through the sight glass on the manway and noticed the agitator had stopped. Knowing that the agitator was supposed to run while cooling, he turned it back on.

The agitation mixed the stagnant layers of hot resin and liquid solvent. The solvent vaporized, and quickly increased the pressure inside the kettle; this triggered the kettle's high-pressure alarm. Within a few seconds, liquid resin and flammable solvent vapor were ejected from the manway, which quickly filled the enclosed room with white vapor. The operator tried to turn off the agitator, but failed because he could not see and had been sprayed with hot resin. He then evacuated. About 2 minutes after the release began, the vapor cloud ignited and exploded. One employee was killed, eight others required medical attention. The resin building was destroyed. (See Figure 1)

Did You Know?

- Agitators can stop due to mechanical, power or control failures. Agitator failure may be detected by the control system, or through visual inspection.
- When some mechanical failures occur, the agitator motor can be running, but there is no mixing.
- Certain process steps, such as sampling, may require the agitator to be temporarily stopped. Operating procedures need to explain when to stop and restart agitation.
- Adding a volatile material or solvent to a process above the solvent's boiling point can produce rapid boiling and increase pressure.
- Agitation moves material to the cooling surfaces. When agitation is stopped, cooling is also reduced.
- When the agitator is restarted, volatile materials may vaporize and increase the reactor pressure.
- The decision to restart the agitator depends on many factors such as how long it has been off, the materials in the process, and others. (See the August 2018 Beacon)
- Process Hazard Analyses (PHAs) should include agitator failure and restart as a topic of review and discussion.

What Can You Do?

- Operating chemical processes requires careful monitoring of the process variables: temperature, pressure, and agitator status.
- When the procedure directs you to stop the agitator and take an action, read the entire step to determine whether to restart it or not after the action is completed.
- If the agitator stops or you find it did not restart, contact your supervisor to determine the correct action.
- During PHAs, agitator failure must be carefully reviewed. There are many variables to determine the hazards and proper corrective actions.

When the agitator stops – Ask for help!!

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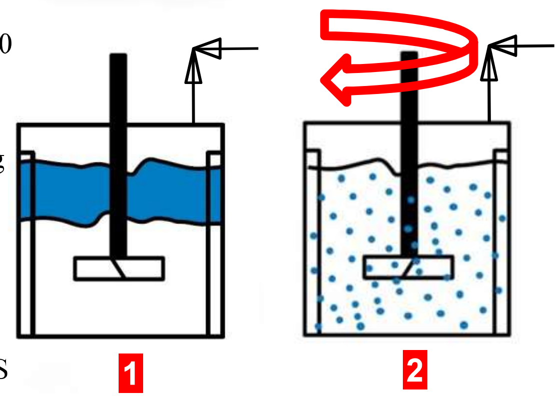
Messages for Manufacturing Personnel

What if your agitator fails?

August 2018

In 1993 in a German factory, o-chloronitrobenzene was reacted with caustic soda dissolved in methanol to produce o-nitroanisol in a 36 m³ (9500 US gal) batch reactor. This reaction is exothermic (generates heat), and the addition of caustic normally took place at about 80 °C over 5 hours.



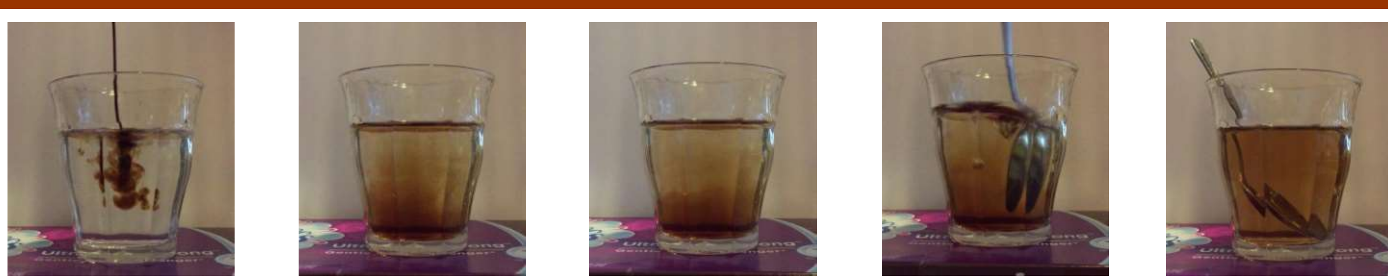
Surprisingly, a batch did not require cooling! In fact, rather than needing cooling to maintain the required batch temperature, steam heating was required. Then it was found that the agitator had not been on during the caustic addition. The reactants were not properly mixed (1). The agitator was started, the unreacted chemicals were mixed (2), and the batch temperature quickly increased, exceeding 160 °C (320 °F). At the elevated temperature a different, also exothermic, reaction occurred. 10 m³ (2650 US gal) of reactor contents were vented to the atmosphere through a pressure relief valve. A large area, including nearby residences, was contaminated. Nobody was injured, but health risk concerns remain. Direct costs were about 40 million DM (in 1993, equivalent to about US $ 38 million today).

Did You Know?

- Chemicals can't react if they do not come into contact with each other. If there is no agitation in a reactor, the reaction will be slow or stop, and unreacted chemicals will accumulate. In an exothermic reaction this is a serious hazard. If you restart the agitator, there will be a lot of unreacted material available and the reaction may be very fast. Your cooling system may not be able to remove the heat fast enough to control the reactor temperature.
- Mixing is clearly important in a vessel containing a multi-phase mixture such as liquid-solid or organic-aqueous liquid phases. It is also important if the materials in the vessel are mutually soluble. In the pictures below, balsamic vinegar, which is completely soluble in water, is added to water without mixing. The vinegar sinks to the bottom of the glass and does not form a uniform solution until the mixture is stirred with a spoon.

What Can You Do?

- If you lose agitation in a reactor, batch or continuous, get technical assistance before re-starting the agitator. Gather some data to share with technical experts to help decide on the appropriate action. For example, how long was the agitator off, what was added to the vessel while it was off, what is the temperature and pressure history of the vessel?
- Recognize that loss of agitation can be a problem in other vessels even if there is no intended reaction. Without agitation, there can be large temperature and concentration differences in the vessel. This can cause freezing on cooling surfaces, boiling near heating surfaces, precipitation of solids from a solution, or settling of solids from a slurry. Variation in composition of material fed from an improperly mixed vessel to other equipment can cause operating or safety issues in downstream process units.
- Heating or cooling of a vessel without agitation is likely to be inefficient, and temperature indication may be inaccurate if the vessel contents are not mixed.



Reference Gustin, J-L., "How the Study of Accident Case Histories Can Prevent Runaway Reaction Accidents to Occur Again." *IChemE Symposium Series* No. 148, pp. 27-40, 2001.

Keep your reactor agitated for safety!

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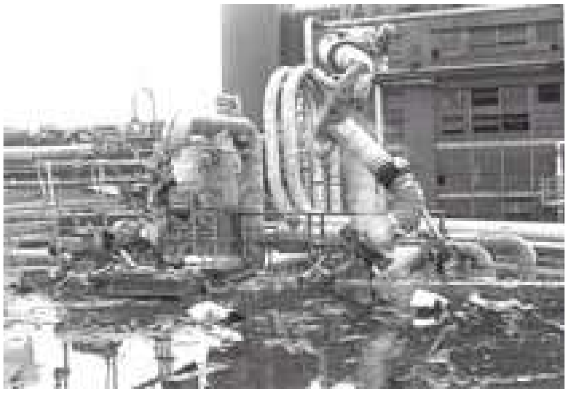
Messages for Manufacturing Personnel
October 2002

It's a bird, it's a plane, it's………………A PUMP!



The Incident

A 75 HP centrifugal pump was operated with both suction and discharge valves closed for about 45 minutes. It was believed to be completely full of liquid. As mechanical energy from the motor was transferred to heat, the liquid in the pump slowly increased in temperature and pressure until finally - the pump failed catastrophically. One fragment weighing 5 pounds was found over 400 feet away. Luckily, no one was in the area so there were no injuries.

Why would events such as this happen?

- This situation is different than operating a pump "deadheaded" – where the suction valve is open but there is no flow through the pump. Here, pressure relief occurs back through the pump suction line.
- In the past, this event likely would have ended with a seal failure - seal leakage would have been sufficient to relieve the pressure. New seal designs are significantly improved. This older "relief system" can no longer be counted upon.
- As processes have become more automated it is now much easier to accidentally start a pump or operate the wrong valve.
- Spare pump arrangements can also be a problem if the "incorrect" pump is started. For example, the "north pump" has valves aligned for operation but the "south pump" is started.

What can I do?

- If you discover a "blocked in" pump in operation, use extreme caution. Shut the pump down remotely; keep people FAR away until it has cooled.
- Use care when starting pumps. Communication about which pump is valved for operation must be very clear.
- Some plants try to have an individual near the pump when it is started. This may not be possible in all situations, but it can eliminate many problems.
- If possible, open the casing drain on a pump that will be out of service for an extended period. But, check to make sure you are not creating another problem (environmental, cost, etc) by doing so!
- And, a routine tour of a manufacturing area can identify many things – a blocked in pump operation is just one of them!

Pumps move liquids for us everyday, but they can also generate heat – a significant hazard if it has no place to go!

Contact us at ccps@aiche.org or 212-591-7319. http://www.aiche.org/ccps/safetybeacon.htm

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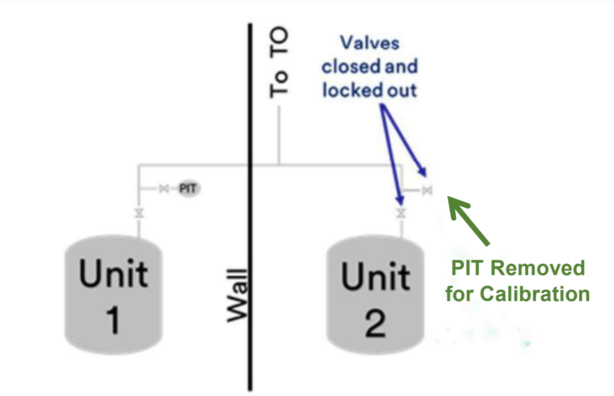
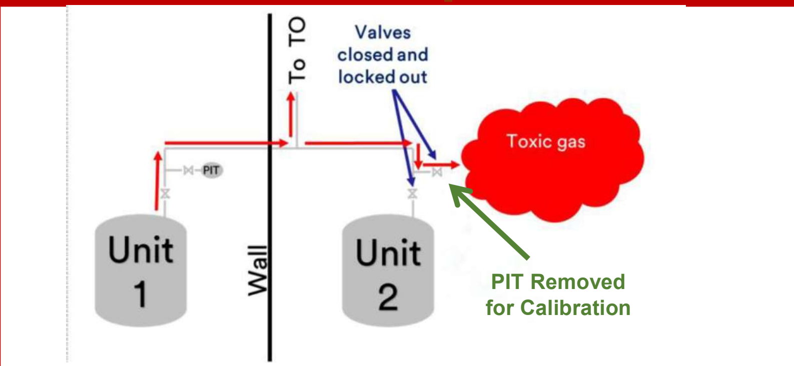
Undetected ball valve failure

March 2019



Units 1 and 2 share a common line to the thermal oxidizer (TO). Calibration was due on several instruments on unit 2. A hand valve was closed and locked out, and a pressure transmitter (PIT) was removed for calibration.



A day or two after unit 2 was locked out, unit 1 began venting toxic gas through the shared line to the thermal oxidizer. The material venting from unit 1 flowed through the vent line toward unit 2. However, the material exited through the valve where the pressure transmitter had been removed.

Upon investigation, it was discovered the ball inside the valve was in the open position, even though the valve handle was in the closed position. (*Note: When moved, the valve handle "felt" like a properly operating valve.)* Fortunately, there were no injuries, but had this event happened on another system, injuries could have occurred

Did you know?

- Any valve can fail, and there are many ways it can fail!
- Valve handles may not always indicate the actual position of a valve. A failure of the handle, stem, ball, or seat can cause a problem
- What happens in one system can affect another and must be considered when altering a system, even temporarily.

What you can do

- Use blinds, plugs or caps when piping will be open, even temporarily.
- Use the line break/opening procedures for those operations, and if line break procedures are not accurate – get them corrected
- Consider the effects of interconnected systems and always 'walk the line' before transferring material.

All valves can fail. Consider double isolation.

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Messages for Manufacturing Personnel

CCPS Sponsors, the Beacon Committee, and volunteer Beacon translators wish all Beacon readers a happy, prosperous ***and safe*** New Year 2010.

Corrosion and Erosion

January 2010

Mechanical integrity is one of the biggest challenges for an effective process safety management program. Think about it – in your plant, there may be hundreds of vessels, thousands of feet of pipe, and hundreds of pumps, compressors, instruments, and other equipment. All of it must be kept in good operating condition to ensure safe, reliable, and profitable operation. Management of corrosion and erosion of process piping and equipment must be a major component of any effective mechanical integrity program.

The pictures show some examples of corrosion and erosion problems which were identified in plant inspections. (1) and (2) – external corrosion of pipes in a plant; (3) – close up of erosion damage to the face of a flange; (4) – close up of eroded body and seat of a gate valve; (5) – erosion damage on the body of a valve.

Do you know?

• ***Corrosion*** is the deterioration of metal by electro-chemical reaction with substances or microbes in its environment. These substances can be process materials contained in a vessel, pipe, or other equipment, or materials in the outside environment – for example, water, salt, or contaminants in the atmosphere. The rusting of steel is an example of corrosion.

• ***Erosion Corrosion*** is the degradation of material surface due to mechanical action, often by impinging liquid, abrasion by a slurry, or particles, bubbles, or droplets suspended in fast flowing liquid or gas.

• Corrosion has been responsible for major losses in the process industries. For example, in 2006, part of a major oil field had to be shut down for several months because of multiple oil spills resulting from severe pipeline corrosion.

What can you do?

• Understand mechanical integrity programs in your plant, and your role in ensuring that these programs are effective.

• Observe pipes, vessels, and other equipment when you are working in the plant. Look for stains on the outside of insulated lines and other signs of damaged or corroded equipment. Follow up to make sure that repairs are made.

• If you are taking equipment or piping apart, look for evidence of corrosion damage – for example, corrosion under insulation, internal corrosion in pipes or other equipment, damage to flanges or valves.

• When replacing pipes, valves, or other equipment, be careful to use the same material of construction.

• Understand the corrosion and erosion corrosion properties of the materials in your plant, and what you must do to minimize corrosion problems.

Watch out for corrosion and keep the chemicals inside the equipment!

 Contact us at ccps_beacon@aiche.org or 646-495-1371.

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