



Hazards and Potential Consequences

Indonesia
December 2011

SAND No. 2011-0720P
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.






Key acronyms

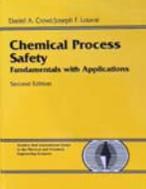
BLEVE = boiling-liquid-expanding-vapor explosion
VCE = vapor cloud explosion
LFL = lower flammable limit
LOC = limiting oxygen concentration





Hazards/consequences resources

D.A. Crowl and J.F. Louvar 2001. *Chemical Process Safety: Fundamentals with Applications, 2nd Ed.*, Upper Saddle River, NJ: Prentice Hall.



Chapter

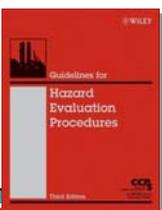
- 2 • Toxicology
- 4 • Source Models
- 5 • Toxic Release and Dispersion Models
- 6 • Fires and Explosions
- 10 • Hazards Identification





Hazards/consequences resources

CCPS 2008a. Center for Chemical Process Safety, *Guidelines for Hazard Evaluation Procedures, Third Edition*, NY: American Institute of Chemical Engineers.



Chapter 3 • Hazard Identification Methods

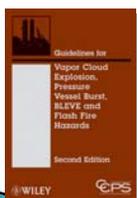
- 3.1 Analyzing Material Properties and Process Conditions
- 3.2 Using Experience
- 3.3 Developing Interaction Matrixes
- 3.4 Hazard Identification Results
- 3.5 Using Hazard Evaluation Techniques to Identify Hazards
- 3.6 Initial Assessment of Worst-Case Consequences
- 3.7 Hazard Reduction Approaches and Inherent Safety Reviews






Hazards/consequences resources

CCPS 2010. Center for Chemical Process Safety, *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards, 2nd Edition*, NY: American Inst. of Chem. Engineers.



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Hazards/consequences resources

Johnson et al. 2003. *Essential Practices for Managing Chemical Reactivity Hazards*, NY: American Institute of Chemical Engineers, accessible free after registration on www.knovel.com.



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Identification of Hazards and Potential Consequences

- ▶ *Process hazard* defined
- ▶ Types of hazards and potential consequences
- ▶ Approaches and methods for systematically identifying process hazards
- ▶ Chemical hazard data

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Identification of Hazards and Potential Consequences

- ▶ *Process hazard* defined



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Process hazard definition

Presence of a
stored or connected
material or energy with
inherent characteristics
having the potential for
causing loss or harm.








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Identification of Hazards and Potential Consequences

- ▶ Process hazard defined
- ▶ Types of hazards and potential consequences



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Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Asphyxiation hazards
- ▶ Combustion hazards
- ▶ Detonation hazards
- ▶ Chemical reactivity hazards
- ▶ Rapid phase transition hazards (BLEVEs)
- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards

These are not mutually exclusive categories.




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Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Simple asphyxiation hazards
- ▶ Combustion hazards
- ▶ Detonation hazards
- ▶ Chemical reactivity hazards
- ▶ Rapid phase transition hazards (BLEVEs)
- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards




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Toxicity and corrosivity hazards

Nature of hazard	Potential exposure of people to materials having toxic and/or corrosive properties
What is required	Presence or generation of toxic/corrosive material + mechanism for physical contact
Typical examples	Chlorine used for water treatment; hydrogen sulfide as hydrocarbon impurity; sulfuric acid used for pH control
Consequences	Contact with toxic/corrosive material can cause various health effects, depending on material characteristics, concentration, route of exposure and duration of contact (see Day 1 information)



Toxicity and corrosivity hazards

Video example	www.youtube.com ; search term Seward ammonia spill
Area of effect	Liquid releases usually very localized; toxic vapor releases can extend many km
How calculated	<ul style="list-style-type: none"> Toxic release dispersion models can be used to calculate release rates, downwind and cross-wind distances with various meteorological conditions Some models can also calculate indoors concentration as a function of time
Free program	http://www.epa.gov/emergencies/content/cameo/aloha.htm



Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Asphyxiation hazards
- ▶ Combustion hazards
- ▶ Detonation hazards
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- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards



Asphyxiation hazards

- ▶ An *asphyxiant* is a gas that can cause unconsciousness or death by suffocation (*asphyxiation*).
 - *Chemical asphyxiants* chemically interfere with the body's ability to take up and transport oxygen
 - *Physical asphyxiants* displace oxygen in the environment
- ▶ *Simple asphyxiants* have no other health effects
- ▶ Most simple asphyxiants are colorless and odorless.



Physical asphyxiation hazards

- ▶ Common industry asphyxiant: Nitrogen N_2
- ▶ Other simple asphyxiants:
 - Hydrogen H_2 Ar
 - Argon, helium, neon
 - Hydrocarbon gases (e.g., methane, ethane, ethylene, acetylene, propane, propylene, butane, butylene) CH_4
 - Carbon dioxide CO_2

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Physical asphyxiation hazards

What is required	Reduced-oxygen atmosphere + situation allowing breathing of the atmosphere
Typical examples	Entry into vessel inerted with nitrogen; oxygen depletion by rusting over time; oxygen depletion by combustion; natural gas leak into enclosed room or area
Video	http://www.csb.gov/videoroom/detail.aspx?vid=11&F=0&CID=1&pg=1&F_All=y
Boundaries	<ul style="list-style-type: none"> • US OSHA: oxygen deficiency exists if concentration is less than 19.5% • ACGIH®: deficiency exists below 18% oxygen at 1 atm (equivalent to a partial pressure pO₂ of 135 torr)

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Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Asphyxiation hazards
- ▶ **Combustion hazards**
- ▶ Detonation hazards
- ▶ Chemical reactivity hazards
- ▶ Rapid phase transition hazards (BLEVEs)
- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards

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Combustion hazards

Nature of hazard	Potential for uncontrolled release of the heat of combustion upon rapid oxidation of a combustible material
What is required	A <u>fuel</u> (pyrophoric or flammable gas; pyrophoric, flammable or combustible liquid; or finely divided combustible solid) + an <u>oxidant</u> (usually atmospheric O ₂) + an <u>ignition source</u> (unless pyrophoric)



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Combustion hazards



Nature of hazard Potential for uncontrolled release of the heat of combustion upon rapid oxidation of a combustible material

What is required A fuel (pyrophoric or flammable gas; pyrophoric, flammable or combustible liquid; or finely divided combustible solid) + an oxidant (usually atmospheric O₂) + an ignition source (unless pyrophoric)

Possible consequences

- Flash fire, pool fire and/or jet fire
- Confined vapor explosion
- Vapor cloud explosion
- Dust or mist explosion
- Toxic combustion products



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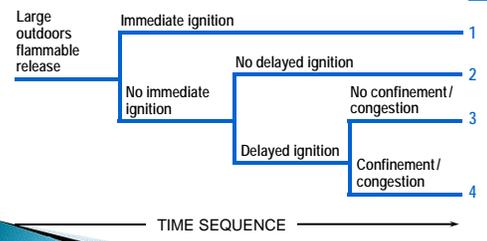
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EXERCISE

Describe each of the four possible outcomes.

Consequence



Large outdoors flammable release

Immediate ignition 1

No immediate ignition

No delayed ignition 2

Delayed ignition

No confinement / congestion 3

Confinement / congestion 4

TIME SEQUENCE →

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Combustion hazards - Some definitions

Combustion A propagating rapid oxidation reaction.

Oxidation In this context, a reaction in which oxygen combines chemically with another substance.

Oxidizer Any material that readily yields oxygen or other oxidizing gas, or that readily reacts to promote or initiate combustion of combustible materials.

Explosion A rapid or sudden release of energy that causes a pressure discontinuity or blast wave.

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Some definitions (continued)

Spontaneously combustible Capable of igniting and burning in air without the presence of an ignition source.

Pyrophoric Capable of igniting spontaneously in air at a temperature of 130°F (54.4°C) or below.

Hypergolic Hypergolic behavior is characterized by immediate, spontaneous ignition of an oxidation reaction upon mixing of two or more substances.

Reference: Johnson et al. 2003

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Combustion hazards



Area of effect Small fires usually have very localized effects; a large fire or a combustion-related explosions can destroy an entire facility and affect nearby surroundings

How calculated Available combustion energy:
 Mass of combustible x heat of combustion *or*
 Mass rate of combustion x heat of combustion

E.g., Ethanol pool fire in a 50 m² dike:

$$[\text{Pool area} \times \text{burning rate} \times \text{liquid density}] \times \text{heat of combustion}$$

$$= (50 \text{ m}^2) (0.0039 \text{ m/min}) (789 \text{ kg/m}^3) (26900 \text{ kJ/kg}) = 4 \times 10^6 \text{ kJ/min}$$

Note: Only ~ 20% of this will be released as thermal radiation.

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Combustion hazards

Free program www.epa.gov/emergencies/content/cameo/aloha.htm
 (can be used to calculate release rates, extent of a flammable vapor cloud, and vapor cloud explosion effect distances)

Online reference Gexcon Gas Explosion Handbook,
www.gexcon.com/handbook/GEXHBcontents.htm

Other references CCPS 2010; Crowl and Louvar 2001
 (See also the Chemical Data Sources at the end of this presentation)

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Flammability limits



LFL Lower flammability limit
 Below LFL, mixture will not burn, it is too lean.

UFL Upper flammability limit
 Above UFL, mixture will not burn, it is too rich.

- Defined only for gas mixtures in air
- Both UFL and LFL defined as volume % fuel in air

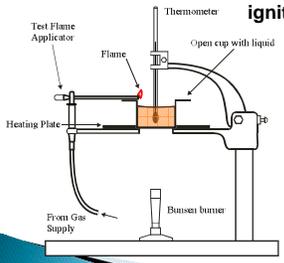
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Flash point



Flash Point Temperature above which a liquid produces enough vapor to form an ignitable mixture with air
 (Defined only for liquids at atmospheric pressure)



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Example values

	<u>LFL</u>	<u>UFL</u>
Methane	5%	15%
Propane	2.1%	9.5%
Butane	1.6%	8.4%
Hydrogen	4.0%	75%

	<u>Flash point</u>
Methanol	12.2 °C
Benzene	-11.1 °C
Gasoline	-40 °C
Styrene	30.5 °C



Limiting oxygen concentration

Limiting oxygen concentration (LOC):

Oxygen concentration below which combustion is not possible, with any fuel mixture, expressed as volume % oxygen.

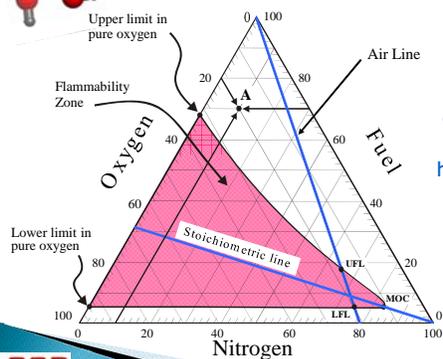
Also called: Minimum Oxygen Concentration (MOC)
Max. Safe Oxygen Concentration (MSOC)

Examples: LOC (volume % oxygen)

Methane	12 %
Ethane	11 %
Hydrogen	5 %



Flammability diagram



Chapter 6 of Crowl and Louvar shows how to prepare and use flammability diagrams



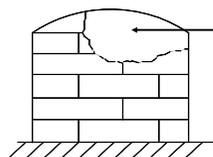
Design Criteria

- 1 Avoid flammable mixtures
- 2 Eliminate ignition sources



Inerting and purging

Purpose: To reduce the oxygen or fuel concentration to below a target value using an inert gas (e.g., nitrogen, carbon dioxide)



E.g., reduce oxygen concentration to $< \text{LOC}$



Inerting and purging options

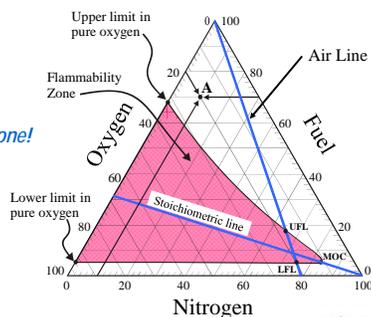
- ▶ Vacuum Purge - evacuate and replace with inert
- ▶ Pressure Purge - pressurize with inert, then relieve pressure
- ▶ Sweep Purge - continuous flow of inert
- ▶ Siphon Purge - fill with liquid, then drain and replace liquid with inert
- ▶ Combined - pressure and vacuum purge; others

See Chapter 7 of Crowl and Louvar for details



Flammability diagram

OBJECTIVE:
Stay out of
Flammability Zone!



Ignition sources



- ▶ Obvious (e.g., flames, welding, hot surfaces)
- ▶ Spontaneous ignition at moderate temp's
- ▶ Electrical sources
 - Powered equipment
 - Static electricity
 - Stray currents
 - Radio-frequency pickup
 - Lightning
- ▶ Physical sources
 - Adiabatic compression
 - Heat of adsorption
 - Friction
 - Impact
- ▶ Chemical Sources
 - Catalytic materials
 - Pyrophoric materials
 - Thermite reactions
 - Unstable chemical species formed in system



Minimum ignition energy

Minimum ignition energy (MIE) The electrical energy discharged from a capacitor that is just sufficient to ignite the most ignitable mixture of a given fuel-mixture under specific test conditions.

Typical values: (wide variation expected)

Vapors 0.25 mJ
Dusts about 10 mJ

- Dependent on test device, so not a reliable design parameter
- Static spark that you can feel: about 20 mJ



Autoignition temperature

Autoignition Temperature (AIT): Temperature above which adequate energy is available from the environment to start a self-sustaining combustion reaction.

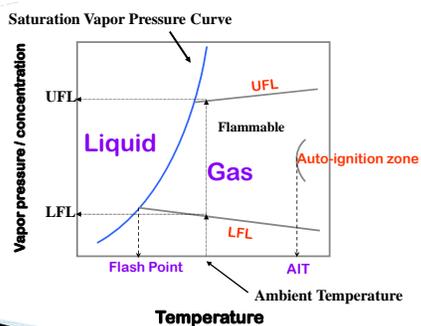
Example values:	AIT
Methane	632 °C
Ethane	472
1-Pentene	273
Toluene	810
Acetaldehyde	185

There is great variability in reported AIT values! Use lowest reported value.

See Appendix B of Crowl and Louvar 2002 for a table of AITs



Flammability relationships



Ignition source control

- ▶ Identify ignition sources
 - Continuous ignition sources; e.g., fired equipment
 - Potential/intermittent ignition sources; e.g., traffic
- ▶ Identify what could be ignited
 - Flammable atmospheres
 - Potentially flammable atmospheres
 - Likely leak/release locations
 - Avenues to unexpected locations; e.g., drains, sumps
- ▶ Analyze for adequate control



DISCUSSION

Which of these two design criteria can be more easily and reliably attained?

1 Avoid flammable mixtures

2 Eliminate ignition sources



Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Asphyxiation hazards
- ▶ Combustion hazards
- ▶ Detonation hazards
- ▶ Chemical reactivity hazards
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- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards



Detonation hazards



Nature of hazard Potential for generating a damaging blast wave by extremely fast chemical reaction

What is required One of two typical mechanisms:
 (1) Direct initiation of a solid or liquid explosive material or mixture, or
 (2) Acceleration of a propagating gas-phase reaction to detonation velocity

Typical examples (1) TNT; picric acid; unstable peroxides; commercial explosives
 (2) Vapor cloud explosion; flame acceleration in a long pipeline containing a flammable mixture



Detonation hazards

Possible consequences

- **Blast wave** (sometimes more than one)
- Shrapnel (usually small fragments)
- Toxic decomposition products

See calculation example for Bursting vessel explosion hazards

Video www.youtube.com; search term **Pepcon explosion**



Detonation hazards - Some definitions

Deflagration A chemical reaction propagating at less than the speed of sound relative to the unreacted material immediately ahead of the reaction front.

Detonation A chemical reaction propagating at greater than the speed of sound relative to the unreacted material immediately ahead of the reaction front.

Deflagration-to-Detonation Transition (DDT) Increase in the propagating velocity of a chemical reaction until the velocity exceeds the speed of sound relative to the unreacted material immediately ahead of the reaction front.

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Deflagration vs Detonation

Deflagration:



Detonation:



Legend:

- Reacted gases
- Reaction / Flame Front
- Pressure Wave
- Unreacted gases

Two graphs show Pressure (P) vs. Distance. The top graph for deflagration shows a broad, low-pressure peak. The bottom graph for detonation shows a very sharp, high-pressure peak labeled 'Shock Front'.

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Chemical reactivity hazards

Nature of hazard Potential for an uncontrolled chemical reaction that can result in loss or harm

Also known as *Reactive chemical hazards*

What is required Any situation where the energy and/or products released by a chemical reaction are not safely absorbed by the reaction environment

Typical examples

- Loss of control of an intended reaction
- Initiation of an unintended reaction

Consequences Fire, explosion, toxic gas release and/or hot material release

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Chemical reactivity hazards

Video

"Introduction to Reactive and Explosive Materials"

Types of chemical reactivity hazards

- Water-reactive
- Oxidizing
- Spontaneously combustible / pyrophoric
- Peroxide forming
- Polymerizing
- Decomposing
- Rearranging
- Interacting (i.e., incompatible)

Reference

Johnson et al. 2003



Chemical reactivity hazards

Some chemicals have more than one reactive property.



For example, organic peroxides can be any or all of:

- ▶ Oxidizing
- ▶ Decomposing (shock-sensitive/thermally unstable)
- ▶ Flammable or combustible
- ▶ Interacting (incompatible with many other chemicals)



Chemical reactivity hazards

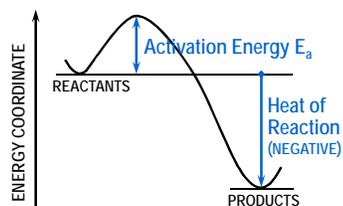
Some types of molecular structures tend to increase chemical reactivity, such as:

- ▶ Carbon-carbon double bonds not in benzene rings (ethylene, styrene, etc.)
- ▶ Carbon-carbon triple bonds (e.g., acetylene)
- ▶ Nitrogen-containing compounds (NO₂ groups, adjacent N atoms ...)
- ▶ Oxygen-oxygen bonds (peroxides, hydroperoxides, ozonides)
- ▶ Ring compounds with only 3 or 4 atoms (e.g., ethylene oxide)
- ▶ Metal- and halogen-containing complexes (metal fulminates; halites, halates; etc.)



Chemical reactivity hazards

Energy diagram for exothermic chemical reaction:



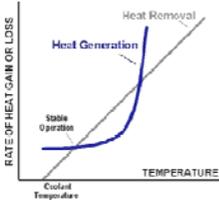
- Lower activation energy barrier Δ faster reaction
- Larger heat of reaction Δ more energy released



Chemical reactivity hazards



Key term to understand:
"Runaway reaction"



For an exothermic chemical reaction:

Reaction rate is exponential $f(\text{temperature})$
 $k = A e^{(-E_a/RT)}$

- Reaction rate increases exponentially with temperature
- If reaction temperature increases, rate increases and more heat is released by exothermic reaction
- If this heat is not removed, it further increases the reaction rate
- Then even more heat is released, etc.
- Temperature can rise hundreds of °C per minute!
- Pressure is generated by product gases and/or liquid boiling
- Reactor may rupture if pressure not safely vented

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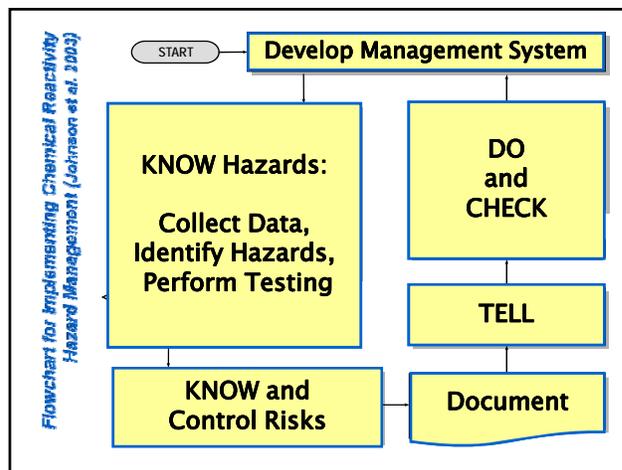
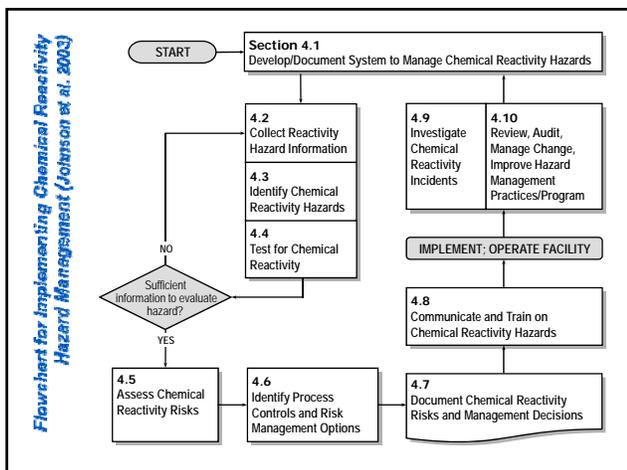
Chemical reactivity hazards



Managing chemical reactivity hazards

- More effort is required to identify and characterize the reactivity hazards
- This may require small-scale testing
- See flowchart on next page

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Chemical reactivity hazards



Key steps to avoid unintended chemical reactions

- Train all personnel to be aware of reactivity hazards and incompatibilities and to know maximum storage temperatures and quantities
- Design storage / handling equipment with all compatible materials of construction
- Avoid heating coils, space heaters, and all other heat sources for thermally sensitive materials
- Avoid confinement when possible; otherwise, provide adequate emergency relief protection
- Avoid the possibility of pumping a liquid reactive material against a closed or plugged line
- Locate storage areas away from operating areas in secured / monitored locations




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Chemical reactivity hazards



Key steps to avoid unintended chemical reactions (continued)

- Monitor material and building temperatures where feasible with high temperature alarms
- Clearly label and identify all reactive materials, and what must be avoided (e.g., heat, water)
- Positively segregate and separate incompatible materials using dedicated equipment if possible
- Use dedicated fittings and connections to avoid unloading a material into the wrong tank
- Rotate inventories for materials that can degrade or react over time
- Pay close attention to housekeeping and fire prevention around storage/handling areas

Source: CCPS Safety Alert, "Reactive Material Hazards: What You Need to Know", 2001





Chemical reactivity hazards

Key steps to control intended chemical reactions

- Scale up very carefully! – Heat generation increases with the system volume (by the cube of the linear dimension), whereas heat removal capability increases with the surface area of the system (by the square of the linear dimension).
- Ensure equipment can handle the maximum pressure and maximum adiabatic temperature rise of uncontrolled reactions
- Use gradual-addition processes where feasible
- Operate where the intended reaction will be fast
- Avoid using control of reaction mixture temperature as a means for limiting the reaction rate
- Use multiple temperature sensors in different locations
- Avoid feeding a material above the reactor contents' boiling point

For more details see D.C. Hendershot, "A Checklist for Inherently Safer Chemical Reaction Process Design and Operation," CCPS International Symposium, NY: AIChE, October 2002





Types of process hazards and potential consequences

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Rapid phase transition hazards

Nature of hazard Near-instantaneous phase transition from liquid to gas, with large volume increase

Also known as Boiling-liquid-expanding-vapor explosion (BLEVE)

What is required Any liquefied gas stored under pressure above its boiling point

Typical example Propane storage tank engulfed in fire with flame impinging on vapor space of tank, weakening the metal to point of failure

Consequences Blast energy from both phase transition and bursting vessel; large tank fragments; huge fireball also if flammable liquid

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Rapid phase transition hazards

Videos www.youtube.com; search term **BLEVE**

Area of effect Can be 1 km or more, depending on size of storage tank(s)

How calculated Calculate each mechanism separately and determine which has greatest effect; multiple mechanisms increases severity:

- Bursting vessel explosion
- Phase transition volume expansion
- Missiles / flying debris
- Fireball thermal radiation if flammable
- Follow-on ("domino") effects



Reference **CCPS 2010**

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Bursting vessel explosion hazards

Nature of hazard Near-instantaneous release of energy stored by a compressed vapor or gas

Also known as Containment overpressurization; Vessel rupture explosion

What is required Vapor or gas at elevated pressure inside some form of containment

Typical examples Overpressurization of a reaction vessel from an unrelieved runaway reaction; ignition of flammable vapors in a tank

Consequences Blast energy from bursting vessel; large vessel fragments thrown; expelling of remaining tank contents; follow-on effects

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Bursting vessel explosion hazards

Videos www.csb.gov; several examples in Video Room, including **Explosion at T2 Labs**

Area of effect Highly dependent on amount of stored energy at time of rupture

How calculated Calculate each mechanism separately and determine which has greatest effect; multiple mechanisms increases severity:

- Bursting vessel explosion (gas / vapor volume expansion)
- Missiles / flying debris
- Release of vessel contents
- Follow-on ("domino") effects



References **CCPS 2010; Crowl and Louvar 2002**

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Bursting vessel explosion hazards



One equation used for calculating blast energy:

$$W_e = R_g T \left[\ln \left(\frac{P}{P_E} \right) - \left(1 - \frac{P_E}{P} \right) \right] \quad \text{Maximum Mechanical Energy}$$

where W_e is the energy of explosion, P is absolute gas pressure in vessel, P_E is abs. ambient pressure, T is absolute temperature.

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Bursting vessel explosion hazards



Another equation used for calculating blast energy:

$$W_e = \frac{(P - P_E) V}{\gamma - 1} \quad \text{Brode's Equation}$$

where W_e is the energy of explosion, P is absolute gas pressure in vessel, P_E is abs. ambient pressure, V is vapor volume, and γ is the ratio of specific heats

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Bursting vessel explosion hazards

EXAMPLE

- ▶ The vapor space of a 30 m³ flammable liquid storage tank is nitrogen-inerted.
- ▶ The nitrogen regulator fails open, exposing the tank vapor space to the full 4 bar gauge nitrogen supply pressure. The tank relief system is not sized for this failure case.
- ▶ If the tank ruptures at 4 bar gauge when it is nearly empty of liquid, how much energy is released?

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Bursting vessel explosion hazards

Data

$P = 4$ bar gauge = 400 Pa gauge = 501325 Pa abs

$P_E = 0$ bar gauge = 0 Pa gauge = 101325 Pa abs

$V = 30$ m³

$\gamma = 1.4$ for nitrogen (dimensionless)



Bursting vessel explosion hazards

Calculation

Using Brode's equation:

$$W_e = \frac{(501325 \text{ N/m}^2 - 101325 \text{ N/m}^2) \cdot 30 \text{ m}^3}{1.4 - 1}$$

$$W_e = 3 \times 10^7 \text{ N-m} = 3 \times 10^7 \text{ Joules}$$



Bursting vessel explosion hazards

Comparison

TNT (trinitrotoluene) has a heat of explosion of 4686 J/g, so a blast energy of 3×10^7 J is equivalent to

$$3 \times 10^7 / 4686 = 6400 \text{ g TNT} = 6.4 \text{ kg TNT}$$



Bursting vessel explosion hazards

Consequences

Figure 6-23 in Crowl and Louvar 2001 (page 268) gives a correlation of scaled overpressure vs scaled distance.

If a control room building is 30 m away from the storage tank, the scaled distance is

$$z_e = 30 \text{ m} / (6.4 \text{ kg TNT})^{1/3} = 16.2$$

From Figure 6-23, the scaled overpressure $p_s = 0.1$, and the resulting overpressure is $(0.1)(101 \text{ kPa}) = 10 \text{ kPa}$



Bursting vessel explosion hazards

Consequences

Table 6-9 of Crowl and Louvar 2001 (page 267) indicates that 10 kPa is sufficient to e.g.

- ▶ break windows
- ▶ cause serious damage to wood-frame structures
- ▶ distort the steel frame of clad buildings



Types of process hazards and potential consequences

- ▶ Toxicity and corrosivity hazards
- ▶ Simple asphyxiation hazards
- ▶ Combustion hazards
- ▶ Detonation hazards
- ▶ Chemical reactivity hazards
- ▶ Rapid phase transition hazards (BLEVEs)
- ▶ Bursting vessel explosion hazards
- ▶ Other physical hazards



Other physical hazards

Physical hazard	Typical examples
Hydraulic pressure	High-pressure hydraulic fluid: <i>Jet spray from pinhole leak can cause severe cuts</i>
Vacuum	Contained sub-atmospheric pressure: <i>Pumping out of a tank or condensing steam with inadequate venting can cause tank implosion</i>

