Chemical Process Safety

Chapter 7: Prevention of Fires & Explosions
Learning Objectives: Chapter 7

1. Understand design criteria to prevent fires and explosions.
2. Understand inerting and purging procedures.
3. Understand how to apply the triangle flammability diagram.
4. Understand static electricity – how it is formed and how to prevent.
5. Understand electrical area classification and what it means for electrical fixtures.
6. Understand fire protection: sprinklers, monitors, fire extinguishers, foam.
Design Criteria

1. Prevent flammable mixtures.

2. Reduce ignition sources.

Need to remember inherently safer design, that is, to reduce inventories, substitute with less dangerous materials, and reduce operating T and P.
Inerting and Purging

Purpose: To reduce the oxygen or fuel concentration to below a target value using an inert gas. Can use nitrogen, carbon dioxide, others. Nitrogen is the most common.

Reduce oxygen concentration to a safe level.
Inerting Procedures

1. Vacuum Purge - evacuate and replace with inert.
2. Pressure Purge - pressurize with inert, then relieve pressure.
4. Siphon Purge - fill with liquid, then drain and replace liquid with inert.
5. Combined: pressure and vacuum purge, others.
Concentration is constant.

Moles oxygen constant

At A: \[ n_{OXY} = y_0 \left( \frac{P_L V}{R_g T} \right) \]

At B: \[ n_{TOT} = \frac{P_H V}{R_g T} \]

\[ y_1 = \frac{n_{OXY}}{n_{TOT}} = \frac{y_0 \left( \frac{P_L V}{R_g T} \right)}{\frac{P_H V}{R_g T}} = y_0 \left( \frac{P_L}{P_H} \right) \]
At end of 2nd cycle:
\[ y_2 = y_1 \left( \frac{P_L}{P_H} \right) = y_o \left( \frac{P_L}{P_H} \right)^2 \]

At end of jth cycle:
\[ y_j = y_o \left( \frac{P_L}{P_H} \right)^j \]  
Eq. (7-6)

Total nitrogen used:
\[ \Delta n_{N_2} = j(P_H - P_L) \frac{V}{R_g T} \]  
Eq. (7-7)
Purge Assumptions

1. Pure nitrogen used.
2. Vessel is well mixed (not a bad assumption for gases).
3. Ideal gas law.
Pressure Purge

Concentration is constant.

Moles oxygen constant

\[ y_j = y_o \left( \frac{P_L}{P_H} \right)^j \]

Faster than vacuum purge, but uses more nitrogen.
1. Evacuate first:

Concentration is constant.

Moles oxygen constant

\[ y_j = y_o \left( \frac{P_L}{P_H} \right)^j \]

Best to evacuate first - uses less nitrogen.
2. Pressurize first:

Concentration is constant.

Moles oxygen constant

\[ y_o = y_{oxy} \left( \frac{P_O}{P_H} \right) \]

\[ y_j = y_o \left( \frac{P_L}{P_H} \right)^j \]

j + 1 cycles
Inerting with Impure Nitrogen

Let $y_{oxy} =$ concentration of oxygen in nitrogen.

Then, the following equation applies:

$$y_j - y_{oxy} = (y_o - y_{oxy}) \left( \frac{P_L}{P_H} \right)^j$$

Eqn. 7-12
Sweep Purging

Well Stirred-Tank Reactor

Mass Balance on Oxygen:

\[ V \frac{dC}{dt} = C_0 Q_v - CQ_v \]

Solution is:

\[ Q_v t = V \ln \left( \frac{C_1 - C_o}{C_2 - C_o} \right) = \text{Total Nitrogen Volume} \]

If \( C_o = 0 \):

\[ Q_v t = V \ln \left( \frac{C_1}{C_2} \right) \]

Uses lots of inert!!

Assumes well-stirred

Eqn. 7-15
Depressurize vessel to atmospheric, then blow air into vessel.
Taking a Vessel Out of Service - 2

(1) Fuel + (z) Oxygen ---> Products

\[ \text{OSFC} = \frac{\text{LOC}\%}{z \left(1 - \frac{\text{LOC}\%}{21}\right)} \]

OSFC = out of service fuel conc.
(1) Fuel + (z) Oxygen ---> Products

\[
N_2 \% = 100 - \frac{z \times LOC\%}{LOC\%} = \frac{z}{100}
\]
Example: A 10,000 gal storage vessel contains butane liquid. We need to get air into the vessel so that maintenance folks can do an internal inspection. How do we do this without creating a flammable atmosphere?

Solution:
1. Need to first pump out liquid butane and reduce pressure to 1 atm. At this point vessel contains pure butane vapor at 1 atm.
2. Find data on butane:
   Table 6-3, for butane, LOC = 12% vol. oxygen

\[
C_4H_{10} + zO_2 \rightarrow CO_2 + H_2O
\]

3. Use Equation 7-17 to estimate butane target concentration:

\[
OSFC = \frac{LOC}{z \left(1 - \frac{LOC}{21}\right)} = \frac{12\%}{13 \left(1 - \frac{12\%}{21}\right)} = 4.31\%
\]
4. Use Equation 7-6 to estimate total cycles.

80 psig nitrogen = 94.7 psia

\[
y_j = y_o \left( \frac{P_L}{P_H} \right)^j
\]

\[
\log \left( \frac{y_j}{y_o} \right) = j \log \left( \frac{P_L}{P_H} \right)
\]

\[
j = \frac{\log \left( \frac{y_j}{y_o} \right)}{\log \left( \frac{P_L}{P_H} \right)} = \frac{\log \left( \frac{0.043}{1.0} \right)}{\log \left( \frac{14.7}{94.7} \right)} = 1.69 \text{ cycles}
\]
How Formed: By separation of two materials

Separation of two sheets of materials:

As materials are separated, electrons must redistribute themselves.

If materials are both conductors, electrons move rapidly.

If one or more materials are non-conductors, the electrons cannot move very fast and final result is a difference in charge. Charge is equal and opposite.
Energies Produced by Various Discharges

Ignition Energies:

Vapors: 0.25 mJ
Dusts: 10 mJ

Energies of various discharges:

Corona: up to 0.1 mJ
Brush: up to 30 mJ
Conical Pile: up to 1000 mJ
Spark: up to 10,000 mJ
Propagating Brush: up to 100,000 mJ

Conclusion:
Formation Mechanisms: Rubbing, Falling, Moving, Flowing

Falling: Dropping dry cellulose powder into an insulated metal tray:

Result: 100 volts for a few grams of powder.
Pouring Xylene thru a funnel:

Result: 100 Volts per 100 ml
Flowing Liquids:

Streaming current results from separation of liquid from pipe. Voltage developed is independent of line length.
If vapor space contains flammable vapor, an explosion may result!
Propagating Brush Discharge

Figure 7-10
1. Grounding and Bonding:

- **Bonding:** Electrically connecting two equipment pieces.
- **Grounding:** Connecting equipment to ground.

Need less than 1 Meg ohm for bonding. Use 7 ohm to insure good mechanical integrity.
Prevention of Static -2
Prevention of Static -3
2. Be careful of:

- Glass containers / vessels / pipes.
- Plastic containers / vessels / pipes / pumps.
- Low conductive liquids: benzene, toluene, xylene, heptane, hexane.

3. Avoid: Free fall of liquids into vessels.
Question: Which item below represents the greatest static electricity hazard?

1. An ungrounded plastic container?
2. An ungrounded metal container?
Static Electrical Hazards

Question: Which item below represents the least static electricity hazard:

1. A grounded plastic container?
2. A grounded metal container?
Fire Protection:  Electrical Area Classification

**Group 1:** Locations with flammable gases or vapors.

**Group 2:** Locations with flammable dusts.

**Group 3:** Locations with flammable fibers.

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**Division 1:** Flammable concentrations are normally present

**Division 2:** Flammable concentrations present only under abnormal situations. Flammable materials normally contained in the closed systems.
Videotape discusses XP (eXplosion Proof) fixtures in detail.
For flammable materials within buildings, use 1 \( \text{ft}^3/\text{ft}^2 \) of floor area.

See Table 7-6 for qualifying details.
Fire Protection: Sprinkler Systems

Closed Head: Typically found in occupied buildings;
Open Head: Activated from a central location.
Monitor nozzles: Fixed location, but can be directed.
Water requirements: 0.25 – 0.5 gpm/ft² protected

See Table 7-7

Closed Head Sprinkler
Fire Protection: Sprinklers

Open Head Nozzle

Deluge System
Fire Protection: Monitor Nozzle
Fire Protection: Fire Extinguishers

Purple K fire extinguisher
(Potassium Bicarbonate)
Fire Protection: Foam
Fire Protection: Storage Vessel
THE END

“THINK SAFETY”!