“Inerting” refers to the removal or prevention of combustible mixtures in vessels

- Perfect mixing assumption
- Buoyancy effects can impede perfect mixing
Hot Work Safety: Hazards

- Fires and explosions
- Asphyxiation
Hot Work Safety: Standards and Guidelines

- NFPA 51B: *Fire Prevention during Welding, Cutting and Other Hot Work*
- NFPA 69: *Explosion Prevention Systems*
- AWS F4: *Safe Practices for Welding and Cutting of Containers and Piping*
- API 2015: *Safe Entry and Cleaning of Petroleum Storage Tanks*
- NFPA 327: *Procedures for Cleaning or Safeguarding Small Tanks without Entry*
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Design Strategy for Inerting Process Vessels

1. Specify the Inerting Design Objective
2. Select the Inerting Medium and Method
3. Determine the Minimum Quantity of Inert Gas
4. Promote Good Mixing During Inerting Procedure
5. Verify with Atmospheric Monitoring
Purging and Inerting of Process Vessels

- **Purging**
  - Number of volume exchanges

- **Blanketing**
  - Make-up flow rate

- **Control volume analysis**
  - Perfect mixing assumption
Departures from Perfect Mixing Caused by Buoyancy

- Unexpected intrusion of air into inerted vessel
- Internal obstruction creates stagnant pocket of flammable gas
- Density stratification during inert blanketing
Size and Shape Influences
Mixing Patterns

Stack effect

Stagnant zones
Densimetric Froude Number

\[ Fr = \frac{V}{\sqrt{\rho'gD}} \]

- \( V \), characteristic velocity
- \( \rho' = [\rho_a - \rho_0] / \rho_0 \), modified density
- \( \rho_a \), ambient gas density
- \( \rho_0 \), inert gas density
- \( g \), gravitational acceleration
- \( D \), characteristic dimension
Geometric Factors

- **Openings**
  - Promote outward flow of light gas

- **Aspect Ratio**
  - Large height/diameter promote flow of light gases

- **Flow obstructions**
  - Can create stagnant zones
Imperfect Mixing in a Large Vessel

Inert gas

Stagnant zone
Case Study #1

Unexpected intrusion of air into a vessel with an inert atmosphere blanket

- Nitrogen blanket temporarily stopped
- Contractors to remove residual polypropylene with vacuum hose
- Manway open for several hours
- Air displaced N₂
- Flammable mixture formed with residual flammable gas
- Ignition source: smoking materials
- Flash fire causing one fatality
Prevent Leakage into or out of Vessel

- Maintain continuous nitrogen flow
- Nitrogen flow Fr > 1 to avoid air intrusion
- Beware asphyxiation hazard
Case Study #2

Internal obstruction creates a stagnant pocket of flammable gas

- Reactor vessel recently contained ethylene oxide
- Contractors to remove paint from manway with grinder
- Tank blanketed with $N_2$
- CGI measurements taken before beginning hot work
- Abandoned pipe connected to the bottom was not identified
Internal obstruction creates a stagnant pocket of flammable gas

- CGI sample tube did not reach tank bottom
- Ethylene oxide “hid” in the blinded pipe section during the nitrogen purge
- Ethylene oxide (denser than $N_2$), migrated out of the pipe via natural convection and diffusion into the lower section of the vessel
Anticipate Stagnant Zones

- Look for dead ends
  - Blinded connections
  - Baffles
  - Distribution plates

- Aggressively sample the vessel atmosphere
  - Bottom or floor
  - Behind obstructions
Density stratification during blanketing: lighter nitrogen blanket on top of a heavier fuel-air mixture

- Reactor was first rinsed with water, then with xylene
- Vessel blanketed with nitrogen
- Work required an oxyacetylene cutting torch
- Not all of the penetrations into the pipe had been blinded off
- Some organic solid (crust) was observed on the vessel walls and on the internal steam coils
Case Study #3 (cont.)

- Boiler was started to supply steam to another process
- Leaky valve allowed steam into vessel steam coils
- Hot coils volatilized solvent trapped in the solid crust
- Solvent vapor ignited from the welding torch resulting in a flash fire and explosion
- The nitrogen blanket did not sweep air out of the vessel, it only provided a gaseous barrier on top
Avoid Density Stratification

Use gas buoyancy to promote good mixing

- If inert gas is less dense than vessel atmosphere:
  - Inject inert gas from the bottom
  - Extract it from the top

- If inert gas is more dense than vessel atmosphere:
  - Inject inert gas from the top
  - Extract it from the bottom
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Consider Buoyancy Effects

- Determine the relative gas densities
  - Molecular weights
  - Temperature

- Rank the gases from heaviest to lightest

- How can buoyancy interfere with good mixing?
Lessons Learned

- Prevent leakage into or out of vessel
- Anticipate stagnant zones
- Avoid density stratification
- Promote good mixing
- Perform aggressive air monitoring