# INERTING AND PURGING VESSELS AND EQUIPMENT

## Table of Contents

Page

1.0 SCOPE ..... 2
1.1 Hazards ..... 2
1.2 Changes ..... 2
2.0 LOSS PREVENTION RECOMMENDATIONS ..... 2
2.1 Process Safety ..... 2
2.2 Sources of Inert or Purge Gas ..... 2
2.3 Inerting Operations ..... 3
2.3.1 General ..... 3
2.3.2 Inerting Systems ..... 4
2.4 Purging Operations ..... 5
2.4.1 General ..... 5
2.4.2 Inert Gas Purging ..... 5
2.4.3 Steam Purging ..... 5
2.4.4 Air Purging ..... 5
2.5 Equipment and Processes ..... 5
2.6 Operation and Maintenance ..... 6
3.0 SUPPORT FOR RECOMMENDATIONS ..... 6
3.1 Inerting and Purging Principles ..... 6
3.1.1 Limiting Oxygen Concentration (LOC) Tests ..... 7
3.2 Inerting ..... 8
3.2.1 Inert Gas Sources ..... 9
3.2.2 Methods of Application ..... 10
3.2.3 Inerting Systems ..... 11
3.2.4 Tank Blanketing ..... 13
3.3 Purging ..... 14
3.4 Monitoring Equipment ..... 14
3.4.1 Oxygen Analyzers ..... 14
4.0 REFERENCES ..... 15
4.1 FM ..... 15
APPENDIX A GLOSSARY OF TERMS ..... 15
APPENDIX B DOCUMENT REVISION HISTORY ..... 15

## List of Figures

Fig. 3.1. Flammability diagram ..... 7
Fig. 3.2.3-1. Typical process vessel inerting system ..... 12
Fig. 3.2.3-2. Oxygen control limits ..... 12
Fig. 3.2.4. Typical tank blanketing arrangement ..... 13

## List of Tables

Table 2.3.1.2.1. Limiting Oxygen Concentration (LOC) Safety Factors ..... 3
Table 3.2. Common Inert Gases ..... 9

## 1.0 SCOPE

This data sheet provides guidance for inerting and purging operations to reduce the likelihood of fires and explosions by the individual or combined use of inert gas, air, and steam in enclosed or semi-enclosed spaces such as tanks, process vessels, piping, or other process equipment containing flammable vapor or gas, combustible dust, or hybrid mixtures.

This data sheet does not apply to the following:

- Purging enclosures for electrical equipment in hazardous locations (see Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*).
- Purging operations for fuel-fired equipment (see the applicable equipment-specific data sheet).
- Dilution of combustible dust by inert dust (phlegmatization).

### 1.1 Hazards

Fires and explosions are the main hazards associated with processes and equipment that present flammable/explosive atmospheres, either by containing flammable vapor/gas, combustible dust, or a combination of them at concentrations between their lower and upper explosive limits (LELs and UELs).

### 1.2 Changes

**January 2022.** This document has been completely revised. Significant changes include the following:

A. Changed the title from “Inerting and Purging of Tanks, Process Vessels, and Equipment” to “Inerting and Purging Vessels and Equipment.”

B. Reorganized the document to provide a format that is consistent with other data sheets.

C. Added new recommendations and updated existing ones to align with current codes, standards, and industry practices. New recommendations include guidance on inerting operations for vessels and equipment, as well as monitoring and inerting systems.

D. Added information to support new recommendations (Section 3.0).

## 2.0 LOSS PREVENTION RECOMMENDATIONS

### 2.1 Process Safety

2.1.1 Conduct a process hazard analysis (PHA) for inerting/purging operations with a detailed evaluation of all potential scenarios and failures considering all modes of operation as well as prevention and mitigation measures. This includes conditions during startup and shutdown. See Data Sheet 7-43, *Process Safety,* for additional information and PHA methodologies.

### 2.2 Sources of Inert or Purge Gas

2.2.1 Provide a reliable source of inert or purge gas capable of suppling at all times the rates and total quantity of gas required to maintain safe process or storage conditions.

2.2.1.1 For storage tanks or gasholders sources, ensure adequate steps are taken to maintain the supply while recharging the tank(s).

2.2.1.2 For gas generators used with combined capacity, ensure the loss of a single unit will not reduce the supply below peak demand requirements.

2.2.2 For critical operations or when required by the process hazard analysis (PHA), provide an inert gas backup source able to deliver the same flow rates and inert gas concentration established by design, to ensure adequate inert gas delivery in the event of failures or maintenance operations of the inert gas source. Use an onsite generator, buffer tanks, gas cylinders, liquid supply, or a combination of these.

2.2.3 Provide pipes, valves, and fittings of materials compatible with the inert gas, suitable for the intended operating pressures, temperatures, and anticipated corrosion or vibration.

2.2.4 Provide inert gas piping systems with all of the following safeguards:

- Moisture traps for low piping points. Arrange piping to drain toward the moisture traps.

- Blowdown connections.
- Protection against freezing, when needed.

2.2.5 Install strainers, screens, or filters where the inert or purge gas system has pressure regulators or flow control valves that are critical for proper regulation. These will prevent rust and scale from entering the control devices.

2.2.6 Install backflow pressure control valves where two or more piping subdivisions are used to limit the flow in any branch. Also provide each subdivision of the main distribution system with a manual shutoff valve.

2.2.7 Provide the discharge of the supply source and each connection between a point-of-use and the main distribution system with a check valve or other suitable device to prevent contamination of the system through a drop in the inert gas pressure or excessive pressure in the vessel.

2.2.8 Do not install cross-connections between the purge or inert gas distribution system and other utility systems, such as compressed air.

2.2.9 Electrically bond and ground the purge or inert gas system to minimize static electricity.

2.2.10 Ensure pipelines of the inert or purge system are cleaned, tested, and inspected before operation.

## 2.3 Inerting Operations

### 2.3.1 General

2.3.1.1 Use only inert gases that are compatible with the material store or process and the construction material of the vessel or equipment. Ensure the gas is free of moisture if it causes excessive corrosion or produces adverse reactions to products.

2.3.1.2 Provide adequate inert gas flow rates to achieve the required oxygen concentration in the inerted space. Consider the following aspects for design calculations:

- Type of inert gas and delivery concentration from the source
- Inerting method
- Operating/storage pressure and temperature conditions
- Recommended limiting oxygen concentration (LOC) value, including safety factors (see 2.3.1.2.1)
- Potential inert gas leakages
- Inert gas peak demands
- Uncertainty of measuring devices

See Section 3.0 for additional information.

2.3.1.2.1 Apply limiting oxygen concentration (LOC) safety factors in accordance with Table 2.3.1.2.1 and Section 2.3.1.2.2 to ensure LOC values are always maintained below limits to protect against unexpected upset conditions or operating errors.

*Table 2.3.1.2.1. Limiting Oxygen Concentration (LOC) Safety Factors*

| *Type of Oxygen Monitoring and System Control* | *LOC Safety Factors* | |
|---|---|---|
| | LOC ≥ 5% | LOC < 5% |
| Continuous monitoring and automatic controls | 2% vol below worst credible LOC | 60% of the LOC |
| Not continuous monitoring and not automatic controls | LOC ≥ 7.5 % | LOC < 7.5% |
| | 4.5% vol below worst credible LOC | 40% of the LOC |

2.3.1.2.2 Consider the following aspects before a safety factor is established:

A. Process conditions, such as the time to raise the oxygen concentration in the enclosure in case of an inert system failure.

B. Time needed for operators to react after alarm activation.

C. Sensitivity and uncertainty of the equipment used to detect oxygen levels.

2.3.1.3 Provide the inert atmosphere with a monitor system to ensure safe conditions are maintained in the enclosure space using the following options and arrangements:

A. A continuous oxygen monitor system. Arrange the monitor's sample points throughout the vessel or equipment to ensure representative samples from the enclosed atmosphere are taken.

B. Inferential methods such as flow rates, pressure, time, etc. For these methods, implement all of the following prior operation:

1. Include them in the process hazard analysis (PHA) to determine potential scenarios and consequences.

2. Thorough analysis of the relationship between the oxygen concentration and the control parameters.

3. Verification of the inferential method using actual oxygen measurement for validation prior initial use and then have them confirmed periodically.

For operations determined by the process hazard analysis (PHA) as having very high severity or frequency, continuous oxygen monitor systems are preferred. The reliability of the system should be determined according to the PHA.

2.3.1.3.1 Interlock the monitor system to alarm at predetermined levels and shut down or provide corrective actions when unsafe conditions are approached.

2.3.1.4 Ensure the explosive level or oxygen concentration is maintained throughout the system during the introduction/exhausting of the inert gas. Multiple inlets and outlets can be used to promote diluent distribution.

2.3.1.4.1 Avoid high-velocity inert gas streams to prevent agitation of the product and generation of static electricity.

2.3.1.5 Provide alarms on low flow or loss of inert gas pressure. Arrange the alarms to sound at a constantly attended location.

2.3.1.6 Provide process and storage vessels that require inerting with adequate arrangements to prevent the entry of air into the inert atmosphere and the escape of flammable gases and vapor. Ensure the vessel is regularly tested for leaks. Base the frequency of testing on operational conditions and leakage history.

2.3.1.7 Provide inerting in tanks with monomers containing inhibitors (hydroquinone, methyl ether of hydroquinone, etc.) according to the oxygen concentration required in the tank head space to maintain the inhibitor's activity.

Polymerization inhibitors stabilize reactive monomers and prevent spontaneous polymerization. Certain inhibitors used to prevent polymerization of monomers may be rendered ineffective unless there is sufficient oxygen in the atmosphere. Polymerization during storage may be prevented by determination of inhibitor content, oxygen level in the vapor space, polymer content, and monomer temperature on a routine basis.

### 2.3.2 Inerting Systems

2.3.2.1 Design inerting systems with a continuous oxygen monitoring and automatic inert gas addition to maintain oxygen levels within specified limits. Ensure design basis and calculations are maintained for future operational changes or reference.

2.3.2.2 Design inerting systems, including inert gas supply (see 2.2.2), with a reliability commensurate with the hazard.

2.3.2.2.1 If a system with a safety integrity level (SIL) is required per the process hazard analysis (PHA), design, operate, test, and maintain it in accordance with the relevant ISA/IEC standards. See Data Sheet 7-45, *Safety Controls, Alarms and Interlocks (SCAI)*, for additional information.

2.3.2.3 Verify and validate the installed inerting system prior to operation to ensure it performs according to design.

2.3.2.4 Ensure the inerting system is included in the management of change (MOC) and incident investigation program to verify changes to the system do not compromise the original design and any incident is investigated to prevent reoccurrence. See Data Sheet 7-43, *Process Safety*, for additional information.

2.3.2.5 Operate, maintain, and test the inerting system in accordance with specifications and manufacturer recommendations to ensure the integrity and reliability of the system is maintained throughout its service life.

### 2.4 Purging Operations

#### 2.4.1 General

2.4.1.1 Before any purging operation is begun, completely drain the contents of tanks, vessels, piping, and equipment to a safe location or containment area. Block and lock out valves supplying ignitable liquid, flammable gas, or any other material into the vessel.

2.4.1.2 When purging to remove combustibles, monitor the explosive limits of the materials to verify the maximum flammable vapor concentration is less than 25% of the lower explosive limit (in air).

#### 2.4.2 Inert Gas Purging

2.4.2.1 Provide, at the purge gas inlet and outlet, connections to a pressure gauge or manometer to indicate conditions within the equipment being purged. Avoid positive or negative pressure outside of safe limits.

2.4.2.2 In sweep-through purging, maintain a slight positive pressure.

2.4.2.3 Use combustible gas indicators and oxygen analyzers to monitor the purging operation. After purging is completed and air introduced, maintain the atmosphere in the enclosure below 25% of the lower explosive limit. If vapor exceeds safe levels, introduce inert gas and resume purging.

#### 2.4.3 Steam Purging

2.4.3.1 Before steam is introduced into a vessel or equipment, provide openings to prevent damage from excessive steam pressure.

2.4.3.2 Provide a steam supply at a rate higher than the condensation rate to ensure the steam sweeps the vapor away instead of just condensing on the cool walls of the vessel. This operation will increase the temperature of the equipment, which could be close to the boiling point of water.

2.4.3.3 To prevent implosions or other damage to vessels or equipment, ensure the following recommendations are complied with:

A. Do not pour cold fluids into the tank or equipment during or immediately after steam has been applied. If the possibility of this scenario or others where a sudden cooling of the vessel exists, such as exposure to frigid temperatures or rain, provide the vessel or equipment with a reliable vacuum-relief system.

B. Once the steam purging procedure has been completed, and before closing the equipment and returning it to operation, allow the equipment to cool down, and verify there is no steam trapped inside.

#### 2.4.4 Air Purging

2.4.4.1 Provide ventilators or air movers rated in accordance with the electrical hazard classification of the equipment/area. Refer to Data Sheet 7-32, *Ignitable Liquids Operations*, for additional information.

2.4.4.2 Locate ventilators/air movers in a position that allows the air to be introduced and moved throughout the equipment and be discharged through another opening to a safe location.

Ventilation air can either be blown in at the base of a tank or vessel or pulled through the vessel by an air extractor at the top.

2.4.4.3 When purging to remove combustibles, provide a high enough air flow to create several total air changes per hour (see 2.4.1.2).

### 2.5 Equipment and Processes

2.5.1 Select oxygen monitor analyzers that are suitable for the inerting application. See Section 3.4.1 for additional information.

2.5.2 For flammable gas detectors, see Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*.

### 2.6 Operation and Maintenance

2.6.1 Provide inspection, testing, and maintenance (ITM) and deficiency management in accordance with Data Sheet 9-0, *Asset Integrity*, and the manufacturer's recommendations. At a minimum, include the following elements and activities in the program:

A. Inert gas system for leakage

B. Supply systems (operating sequence tests including all components)

C. Sensors test and calibration

D. Visual inspections to strainers, screens, or filters installed in inert gas lines to prevent rust and scale from entering to control devices

E. Alarms and interlocks (low/high concentration alarms, flow alarm, combustible or process emergency shutdown)

2.6.1.1 Test all components and subsystems both individually and as a complete system, including the interface with process controls and support systems. Verify operation and setpoints of inert gas and oxygen concentration sensors are in accordance with manufacturer's instructions.

2.6.2 Provide emergency procedures for sudden loss of inert gas and deviation of combustible gas or oxygen atmosphere from setpoint trending to a combustible atmosphere.

2.6.3 Establish jumper/bypass procedures for bypassing operations according to Data Sheet 10-8, *Operators.* Ensure process hazards, notification of all affected operators, contingency plans to reduce the risk, and formalized plans to complete repairs are included.

## 3.0 SUPPORT FOR RECOMMENDATIONS

### 3.1 Inerting and Purging Principles

Vessels and equipment containing flammable gasses or ignitable liquids have the potential of fires and explosions due to the presence of combustible vapor-air mixture atmospheres when the concentration of the material is within the flammable/explosive limits. The terms "flammable" and "explosive" are used interchangeably because unconfined vapor mixed in air will burn, while confined vapor will produce an explosion.

The flammability diagram shown in Figure 3.1 represents a methane-air mixture with nitrogen as inert gas. It can be observed that the flammable/explosive range of the mixture is located within the ABC triangle. Lower and upper explosive limits (LEL/UEL) can be found at the intersection of the air line and the flammable range area. Any point outside of this area represent mixtures that cannot be ignited.

Prevention of fires and explosions can also be achieved by controlling the oxygen concentration in the enclosure atmosphere. The limiting oxygen concentration (LOC) is the concentration of oxygen in a specific fuel-air-inert gas mixture where a fire/explosion cannot occur. LOC values are different for each material and depends on the type of inert gas used, temperature, and pressure of the system. For example, for a methane-air mixture inerted with nitrogen at atmospheric temperature and pressure conditions, the LOC value is 12% vol, as shown in Figure 3.1.

Basically, inerting and purging operations are used to prevent fires and explosions of vapor and gases by:

- Reducing the oxygen concentration in the space to a point where combustion cannot be supported (LOC),
- Reducing the fuel concentration below the LEL (lean mixtures), or
- Increasing the fuel concentration above the UEL (rich mixtures)

Systems that operate with fuel concentrations above the UEL are typically used in refineries or other locations where a source of fuel gas (i.e., natural gas, methane, etc.) is readily available. It is commonly applied in flare or vent headers operations. Systems containing high concentrations of fuel must consider an operational safety factor for fuel concentration to prevent the mixture from entering the flammable region. If the oxygen concentration in a system is constrained below a value which corresponding upper explosive limit (UEL) is U, a safety factor should be applied such that the fuel concentration in the system is maintained at not less than 1.7 U. However, testing should be conducted to establish the UEL as a function of the stream compositions for worst credible operating conditions.

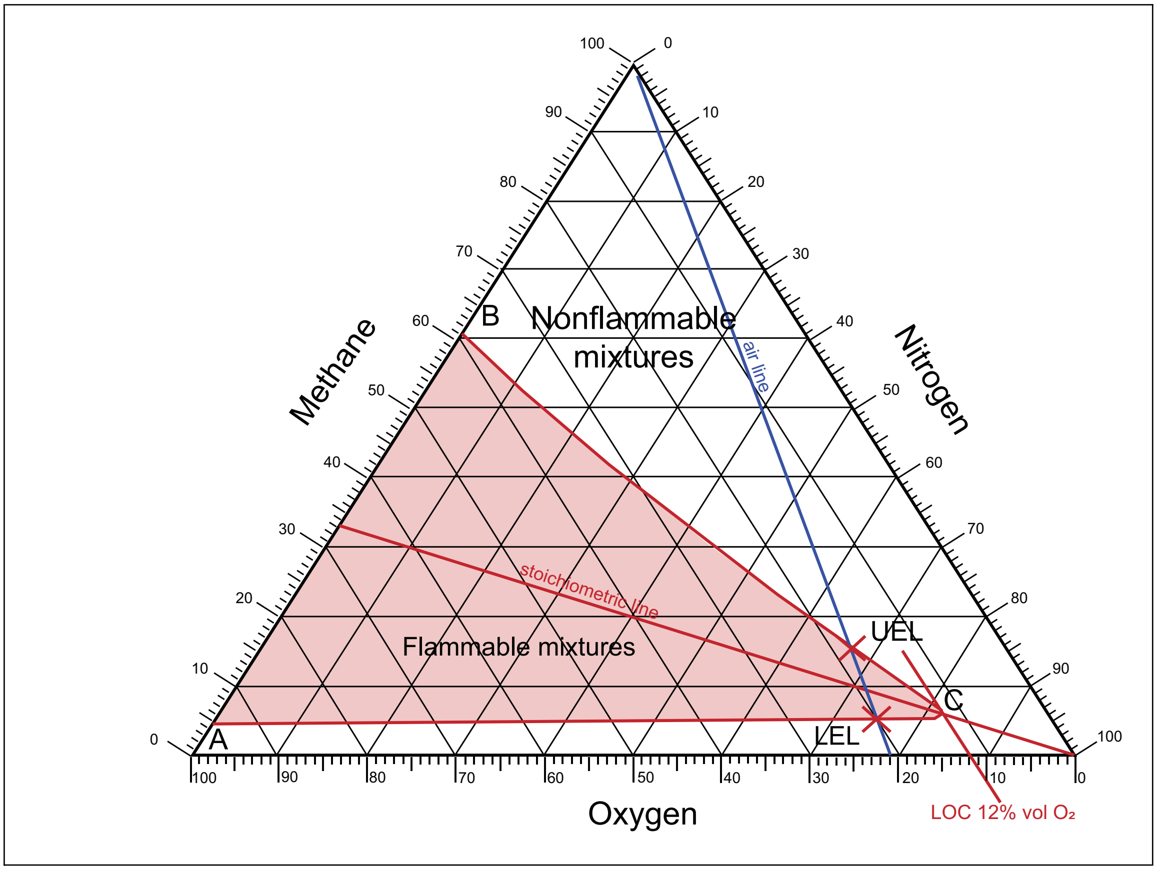


*Fig. 3.1. Flammability diagram*

Hazards associated with fuel rich mixture systems include flammable atmospheres if air leaks or temperature drops, allowing the enriched vapor to condense. Also, a cool flame combustion event may occur with certain materials in the fuel mixture (i.e., ethers, ketones, hexane, etc.), which could transition into a normal combustion flame if enough air is added to the mixture.

Prevention of explosions for combustible dust materials have some differences from flammable gases and vapor. Inert atmospheres can only be achieved by reducing the oxygen concentration or by phlegmatization, which consist in the dilution of the combustible dust concentration using an inert dust material such as carbonates, phosphates, rock dust, etc. Phlegmatization is a rarely used inerting method because of the large quantities of inert dust needed, 50-75% of total concentration, thus it is not further discussed in this data sheet.

Mixtures of combustible dust and flammable gases or vapor (hybrid mixtures) present a unique challenge for inerting operations. These mixtures can be explosive even below the lower explosivity limits of the individual components. Therefore, mixture testing is an important component to determine the specific value of oxygen or fuel concentration to be maintained within the vessel or equipment. Also, knowledge of the minimum ignition energy (MIE) of the combustible dust and the gaseous fuel is important to determine the ignition behavior of the hybrid mixtures.

### 3.1.1 Limiting Oxygen Concentration (LOC) Tests

LOC values are determined using different experimental methods for gases/vapor and combustible dust. In the open literature or chemical databases LOC values can also be found; however, care should be exercised when using those values unless the method used is known to give comparable results to the current experimental methods, and the LOC value has been determined under the specific operating or storage conditions. For dust materials is also important to consider physical characteristics such as particle size and potential ignition sources.

Gases and vapor are currently tested using either ASTM E2079-19 or EN 1839 standards. The reported LOC values of materials tested using these two standards can have some differences between them, basically due to the different methodologies applied. ASTM E2079-19 introduce materials at specific concentrations of fuel-air-inert gas, which varied throughout trials, under controlled pressure and temperature conditions in spherical vessels with a capacity of 4-120 L. Different ignition source may be used, such as chemical ignitors, fuse wires, carbon spark, etc., depending on general conditions and sensitivity of materials tested.

LOC values in EN 1839 are determined using two methodologies, the tube method (method T) and the bomb method (method B). The tube method uses mixtures of fuel-air and inert gas at different concentrations, which is introduced at the bottom of an upright cylindrical test vessel, to perform different ignition tests until the mixture sample fail to ignite. The test vessel is made of glass or other transparent material such as polycarbonate, with an inner diameter of about 3.1 in. (80 mm) and a minimum length of 12 in. (300 mm). The vessel is equipped with an inlet pipe with a three-way valve for the test mixture, located at the bottom, and an outlet pipe and pressure vent in the upper part. A series of induction sparks between two electrodes is used as the ignition source. The bomb method test mixtures in a cylindrical or spherical vessel and can be perform at different temperature and pressure conditions. Vessels are made of stainless steel or any other material free of any catalytic effect and resistant to corrosion from the initial gas mixture and the products of combustion. The test vessel and any equipment (valves, ignition source, transducer etc.) is designed to withstand a maximum overpressure of at least 220 psi (15 bar). In general, the tube method gives a wider explosion range and differences in the explosion limits and limiting oxygen concentration determined by the two methods can vary by up to 10%.

Over the years, some other methodologies have been used, like the one reported in Bulletins, 503 (1952), 627 (1965) and 680 (1985) from the Bureau of Mines. LOC values on those publications were obtained in a 2 in. (5 cm) diameter and 6 ft length flammability tube with upward flame propagation at atmospheric pressure and temperature. Recent comparisons have demonstrated that modern test provide more accurate LOC values than the ones obtained in the flammability tube, which diameter may be too small to mitigate the flame quenching influence, impeding accurate determination of the LOC.

Determination of LOC values for combustible dust are outlined in ASTM E2931-13 and EN 14034-4. The principle of these tests is to determine the limiting oxygen concentration of a dust sample dispersed in a mixture of air/inert gas, in a closed vessel of 20 L or greater. The test is performed under specific particle size, moisture content and ignition source strength, normally at atmospheric pressure and temperature conditions.

Similar to LOC evaluations for gases/vapor, the Bureau of Mines in the Report 6543 (1964), provided LOC values for dust materials. The report summarized experimental data of inerting on ignition of dust dispersion in a partially closed chamber with controlled moisture conditions and particle sizes (most of the samples were 74 microns in size), using different ignition sources.

For LOC dust test, the ignition source, moisture content and particle size play a very important role. Fine dust samples can have lower LOC values than those with bigger particle sizes, as well as different LOC values may be obtained with variations of moisture content in the sample and ignition source strength.

### 3.2 Inerting

Inerting is the process of maintaining a volume of inert gas within an environment that does not support any combustion, which means the oxygen level is maintained at a value below which combustion can occur. To achieve an inert environment within a piece of equipment, the normal atmosphere needs to be displaced with an inert gas until the desired oxygen concentration has been achieved.

The amount of inert gas required, and rate of application will depend upon the amount of oxygen in the gas and maximum permissible percentage of oxygen below which ignition will not occur. This varies with the flammable or combustible materials involved and the inerting medium.

Typical inert gases used for inerting operations are listed in Table 3.2. The choice of inert gas depends on a number of factors, such as compatibility, effectiveness, availability, supply reliability, cost, etc.

*Table 3.2. Common Inert Gases*

| *Inert Gas* | *Description* |
|---|---|
| Nitrogen | Nitrogen is the most used inert gas because of its availability and relatively low cost compared with other inert gases. Nitrogen is available as a compressed or cryogenic gas or may be generated on site from ambient air or other technologies. Nitrogen can react with some metal dust at elevated temperatures (i.e., magnesium). |
| Carbon dioxide | Carbon dioxide is a more effective gas than nitrogen. It is available as a compress gas or as a waste gas from on-site processes. Carbon dioxide can form weak acid in the presence of water vapor which can produce severe corrosion on metal structures. It reacts with amines forming solid deposits and can decompose with some metal dusts such as sodium, magnesium, lithium, etc. |
| Noble gases | Noble gases are less commonly used in inerting operations due to the high cost of these gases. Applications can be limited to those where other gases such as nitrogen or carbon dioxide cannot be used. Argon or helium are unlikely to react or contaminate products. |
| Flue gases | Flue gases from combustion processes may be used considering the oxygen concentration in the mixture can be controlled and special measures have been taken to prevent or minimized oxygen concentration fluctuations. Remotion of any contaminant or flammable gases should be performed before application. Cooling and scrubbing are usually needed to remove contaminants. |
| Steam | Steam needs to be provided at specific pressure and temperature to ensure the oxygen concentration can be reduced in the enclosure atmosphere. Condensation must be considered; it may lead to a pressure drop creating air ingress or a vacuum. LOC values required for steam inerting may be different from those at normal atmospheric temperature. Thus, LOC needs to be determined under conditions that are representative of normal processing temperatures. |

The primary function of the inert gas is to prevent the formation of explosive vapor-air mixtures in enclosed spaces. It also may be used to blanket flammable products in storage tanks or reactors and prevent fires or the formation of explosive mixtures in drying ovens and glove boxes.

Inert gas may be used to prevent dust explosions by keeping the oxygen concentration below that necessary to propagate an explosion. Equipment such as mixers, pulverizers, grinders, conveying systems, dust collectors, and storage bins may be protected in this way.

Inerting also may be used to prevent spontaneous heating of materials or to safeguard operations that must be conducted above the ignition temperature of the material.

### 3.2.1 Inert Gas Sources

There are different options that can be used as inert gas source for purging or inerting operations. Considerations such as total amounts, reliability, purity required, compatibility, etc. needs to be taken into account before a supply source is selected. Some gases can be produced on site using specific technologies, obtained as a process waste, or delivered through a supplier.

**Storage tanks or cylinders**. Inert gases such as nitrogen and argon are commercially available as compressed gases or cryogenic liquids with a purity of more than 99%. Vessel capacities varies from 350 to 13,000 U.S. gallons (1,325 to 49,210 liters). The quantity of product in a vessel is determined by its water capacity and pressure rating. Storage vessels are designed and manufactured according to applicable codes and specifications considering the pressure and temperature at which the inert gas is stored. They can be found in different shapes (vertical, spherical, or horizontal) depending on the site and consumption requirements.

Cylinders are another inert gas source covering a wider selection of high purity gases. They are commonly used for inert/purge operations for small systems that require low flow applications. Cylinders are manufactured according to transportation regulations where specifications such as construction materials, manufacture and testing methods, permitted content gases, etc. are provided. They may be used with individual connections or in groups of several cylinders, where special pipe arrangements are required.

Carbon dioxide or nitrogen in cylinders or bulk tanks is commonly used where the systems to be protected are small, and loss through leakage is slight. These may be the most practical supply even for large installations where no oxygen can be tolerated in the source inert gas.

**Generators.** Nitrogen generators are the most common method used for on-site inert gas production, usually applied for processes where a reliable nitrogen supply is needed or where high purity streams are required, like those in chemical and pharmaceutical plants.

Generators are design based on two technologies, depending on the nitrogen concentration or purity required:

- Membrane (95-98% nitrogen concentration). The generator separates the compressed air into component gasses by passing the air through semipermeable membranes consisting of bundles of hollow fibers. The fibers selectively permeate oxygen, water vapor, and other impurities out of their sidewalls, allowing nitrogen to move through the center to be release as separate gas.
- Pressure swing adsorption (PSA) (up to 99.99% nitrogen concentration). It is an adsorption-based process where molecules bind themselves to an adsorbent. Dual beds with carbon molecular sieve (CMS) are provided in two separate pressure vessels that serve to capture or absorbs oxygen, carbon dioxide and water vapor, letting nitrogen pass through.

Nitrogen generators are typically free-standing units and users need only to connect a standard compressed air line to the inlet of the generator and connect the outlet to the nitrogen line.

Chemical plants that require large volumes of nitrogen may have onsite cryogenic units, which commonly are scaled-down versions of the cryogenic plants used for bulk producers. See Data Sheet 7-35, *Air Separation Processes*, for additional information.

### 3.2.2 Methods of Application

Several inerting methods can be used to create and maintain a noncombustible atmosphere in an enclosed space. To select the best inerting method for the specific process or equipment, a thorough evaluation has to be performed where factors such as material to be inert, inert gas availability and flow rates, design pressure or vacuum of the equipment, type of process (continuous or batch) or storage, have to be considered. In general, inerting methods include fixed-rate and variable-rate or demand applications.

#### 3.2.2.1 Fixed Rate Application

This method involves the continuous introduction of inerting gas into the enclosure at a constant rate, and a corresponding release of inert gas and whatever gas, vapor, or dust has been picked up in the equipment. The rate must be sufficient to supply the peak requirement in order that complete protection can be provided.

Advantages are simplicity, lack of dependence on devices such as pressure regulators, and possible reduced maintenance.

Disadvantages:

- Where the space contains a volatile liquid, a continuous loss of product will occur, due to constant sweeping of the vapor space by the inert gas.
- A large quantity of inert gas is used because it is supplied whether needed or not.
- There may be disposal problems (toxic and other effects) for the mixture that is continuously released.

#### 3.2.2.2 Variable-Rate or Demand Application

Inert methods in this category involves the introduction of inerting gas into an enclosure at a variable rate, dependent on demand to reduce the oxygen concentration to a level where combustion cannot be sustained.

An advantage is that inert gas is supplied only when actually needed, reducing the total quantity required, loss of product, and disposal problems.

A disadvantage is more complex systems than fixed-rate applications with dependence on different controls like oxygen analyzers, flow or pressure control valves that required specific calibration, testing and maintenance activities to ensure the reliability of these systems.

**Pressure Inerting.** This method over pressurized the system with inert gas and then depressurized to atmospheric or initial pressure. The cycle is repeated for a calculated number of cycles until the required oxygen concentration is reached. It is only suitable for system which can be pressurized.

**Vacuum Inerting.** This method is useful if the vessel or equipment to be inerted can withstand a vacuum. This is similar to pressure inerting, but in this case the pressure in the system is reduced to create a vacuum and then released to break the vacuum with inert gas. Several vacuum/break cycles can be repeated until the desired oxygen concentration is reached. This method is suitable for systems that can withstand vacuum but not pressure.

**Sweep-through Inerting.** This process involves introducing an inert gas into the equipment at one opening and letting the enclosure atmosphere contents escape through another opening, remote from the feed point in order to sweep out any residual vapor or gas. The quantity of inert gas required will depend on the physical arrangement. A single pipeline can be effectively inerted with only a little more than one volume of inert gas. However, vessels will require quantities of purge gas much in excess of their volume. If the system is complex, involving side branches through which circulation cannot be established, this method may be impractical and one of the other methods may be more suitable.

**Syphon Inerting.** Equipment may be inerted by filling with liquid (product or water), then introducing inert gas into the vapor space as the liquid is drained. The volume of inert gas required will be equal to the volume of the vessel, and the rate of application will correspond to the rate of draining. This method may not be suitable if the liquid is above its flash point because of evaporation into the space or equipment where air might be trapped inside a void.

#### 3.2.2.3 Peak Demand for Continuous Inerting

Normally, the peak demand for continuous inerting is controlled by the maximum rate of liquid withdrawal and temperature change.

For a vessel containing a liquid, the inert gas demand for liquid withdrawal will be the capacity of the largest pump that can be used to withdraw liquid, or the maximum possible gravity outflow rate, whichever is greater.

The maximum demand from temperature change will occur in outdoor tanks operating at near atmospheric pressure as a result of sudden cooling by a summer thunderstorm. The rate of inert gas supply necessary to prevent vessel pressure from falling significantly below atmospheric pressure can be calculated as follows:

A. For tanks over 800,000 gal (3000 $m^3$) capacity, 2 $ft^3$ of inert gas/hour/$ft^2$ (0.6 $m^3$/hour/$m^2$) of total shell and roof area.

B. For smaller tanks, 1 $ft^3$ of gas/hour/40 gal of tank capacity (1 $m^3$ inert gas/hour/5.3 $m^3$ of tank capacity), or the rate corresponding to a mean rate of change of the vapor space temperature of 100°F (55°C) per hour.

The rates for temperature change and liquid withdrawal must be added together.

In some equipment, such as pulverizers, the rate of inert gas supply necessary to exclude air may be dominated by leakage, and temperature change can be ignored.

### 3.2.3 Inerting Systems

Inerting systems are commonly used for enclosures with atmospheres that require a continuous oxygen monitoring and automatic inert gas addition to maintain specific oxygen limits through precise controls. These systems provide reliable measurement of oxygen levels over a wide range of conditions and automatically activate the inert gas control valve to add inert gas to the process or equipment when limits are exceeded.

Figure 3.2.3-1 shown a process vessel inerting system, where samples from the headspace atmosphere are continuously taken by a sampler device to be conditioned and sent to the analyzer, where the oxygen sensor measures the oxygen content in the gas stream. This value is compared with the setpoint limits, and no actions are taken if values remain under limits. However, if high limits are reached, the analyzer activates the inert gas valve to bring the process under safe oxygen operating limits.

Inerting systems operates using different oxygen control limits to prevent the system to reach or exceed the limiting oxygen concentration (LOC) value determined by experimental test. Figure 3.2.3-2 present the oxygen concentration control limits recommended in an inerting system.

The maximum permissible oxygen concentration (MPOC) is a safety factor used to prevent the process to reach unsafe conditions. At this point the system is expected to trip to initiate a process shutdown or other immediate actions, to ensure oxygen concentration is not rising to dangerous levels. The MPOC is generally accepted to be 2% points below the LOC for LOC values greater than 5% or 60% of the LOC for LOC values lower than 5%. However, a detail risk assessment is recommended to determine specific conditions that may require changes to this safety factors, such as how quick the oxygen concentration can rise in case of failure of the inerting system.

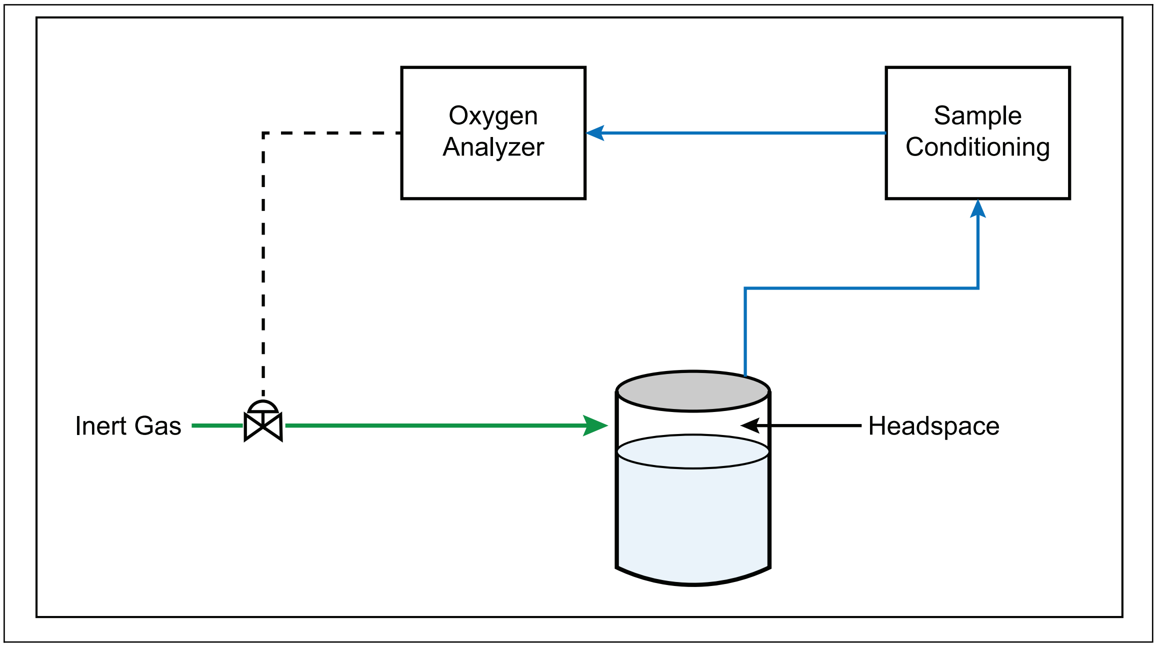


*Fig. 3.2.3-1. Typical process vessel inerting system*

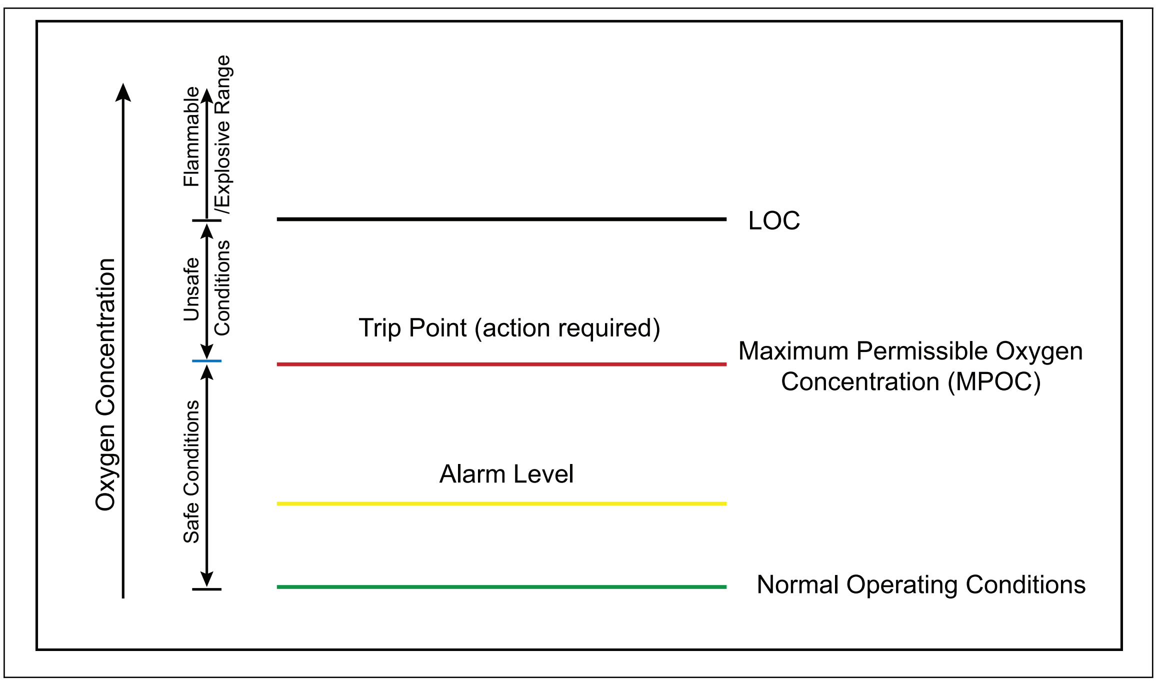


*Fig. 3.2.3-2. Oxygen control limits*

The alarm level is the point where alarms will sound, and operator action is expected to bring the system back to normal operating conditions. This needs to be set below the MPOC and consider monitor sensitivity as well as response time from instruments/equipment and operators.

The design of an inerting system requires a thorough analysis of the process hazards, potential inert gas failure scenarios and the established oxygen concentration limits, to determine the reliability and redundancy of the system needed for the specific application. During the design phase, aspects such as the inerting method, process/storage conditions that may affect the inert atmosphere (i.e., temperature or pressure fluctuations), required system response time, etc. should be considered and evaluated.

Other elements that play an important role in the reliability and operability of these systems include:

- Reliable source of inert gas
- System installation and verification prior to operation.
- Inspection, testing and maintenance programs.
- Management of change, including replacements not in-kind and level of authorization for control limits changes.
- Updated and available documentation.

### 3.2.4 Tank Blanketing

Blanketing is the process where a gas is applied to maintain an inert atmosphere in the vapor space of tanks or process vessels. Different inert gases can be used; however, nitrogen is the most common due to its availability and relatively low cost.

In a tank blanketing (Figure 3.2.4), the inert gas is introduced at the top of the tank to fill the vapor space above the liquid, creating a low positive pressure inside the vessel. This positive pressure also prevents air, moisture, or other contaminants from entering the vapor space and causing product quality degradation.

To maintain the tank pressure within acceptable ranges, tank blanketing valves are used to control nitrogen flow rates based on pressure changes, which may be caused by liquid level or temperature fluctuations. Blanketing valves are commercially available in wide variety and are installed along with pressure/vacuum conservation vents and emergency pressure relief vents.

Conservation vent valves are used to maintain the tank's vapor space within safe operating parameters and to protect the vessel against excessive pressure or vacuum caused by pumping liquid in/out the tank or thermal changes. These can be found as weight loaded, which are rated for low pressures [i.e., 83 in W.C (about 3 psig)], or if the valve needs to be rated for higher pressures, spring-loaded versions are also available.

A blanketing tank operation may need several inerting cycles (injection/release) to reach the required oxygen concentration in the tank vapor space. Each cycle consists of the injection of the inert gas up to a predetermined blanketing pressure setpoint. Variations of liquid level or temperature will produce a decrease pressure in the tank, which will activate a pressure sensor and send the signal to the blanketing valve to open and let more inert gas to enter the tank vapor space until the predetermined pressure is reached again.

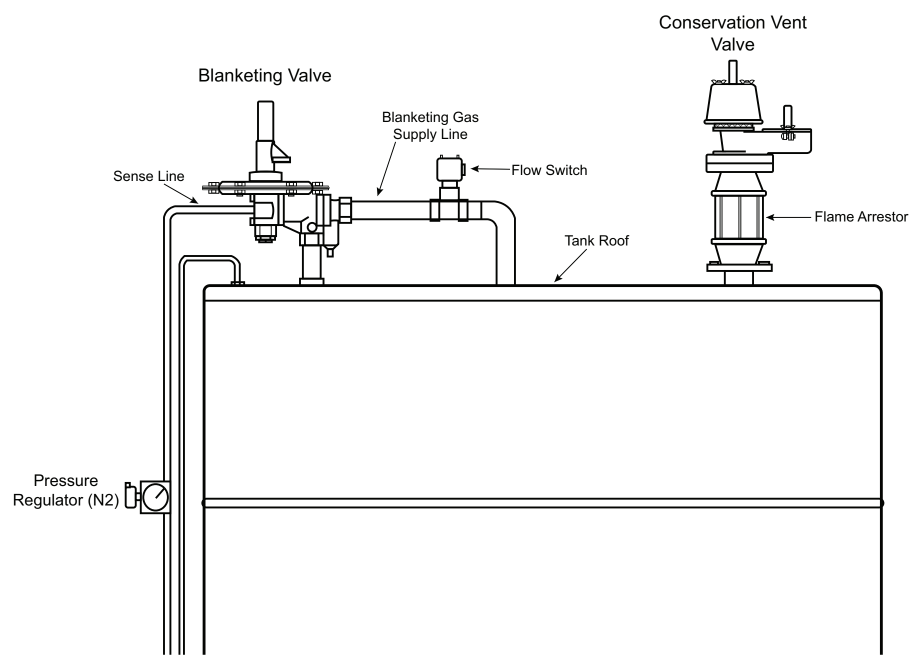


*Fig. 3.2.4. Typical tank blanketing arrangement*

### 3.3 Purging

As used in this data sheet, purging is the act of moving an environment from one condition to another by introducing steam, air, or inert gas while displacing flammable vapor or gas to reduce the flammable concentration to a level that prevents ignition.

Steam purging is commonly used in vessels to sweep residual hydrocarbon materials due to the thermal value of the steam to remove solvents. Steam used for purging needs to be supplied at a rate sufficiently high to maintain the vessel temperature at 160°F (71°C) or higher. Before closing the equipment and putting it back into operation, care must be taken to ensure the equipment is cooled down and there is no steam trapped inside. Otherwise, there is a risk of the vessel collapsing by implosion.

Air purging is used for startup equipment operations (ovens, dryers, etc.) to eliminate fuel vapor and flammable gas that may be accumulated during shutdown, or to ventilate an area to reduce vapor or gas concentration. Air purging could be used before steam purging to help reduce the initial vapor or gas concentration, and at the end for faster cooling of the vessel.

Inert purging may be used to purge tanks or process vessels prior to repair by displacing flammable vapor before air is introduced, and to purge air out before vapor is reintroduced.

Application of purging methods may include occasional or one-time use, like pipe or equipment purging during shutdown for cleaning or maintenance operations.

### 3.4 Monitoring Equipment

#### 3.4.1 Oxygen Analyzers

A critical aspect of an inert atmosphere is the verification and control of the oxygen concentration, commonly performed using measuring instruments. Different technologies are commercially available and special considerations and analysis have to be applied to select the monitor system that is more suitable for the operation and atmosphere conditions.

The majority of oxygen sensors used to quantify oxygen levels for inerting operations are classified into any of the following technologies:

- Electrochemical
- Zirconium
- Paramagnetic

##### 3.4.1.1 Electrochemical Oxygen Sensors

Electrochemical sensors are typically a small partially sealed devices containing two electrodes (anode and cathode) immersed in an aqueous electrolyte solution. The determination of oxygen is based on a chemical reaction within the sensors that generates an electrical output, proportional to the oxygen level content. There are different types of electrolytes available to facilitate the selection of the sensor that is most suited for the particular application.

Electrochemical sensors when exposed to oxygen reduces its operation life due to reaction exhaustion, usually having a lifespan between one to three years, depending on sensor design. Storage within an oxygen-free environment will not increase the lifespan of the sensor.

These sensors have a limited temperature and pressure range and normally require a sampling system if used on high temperature or pressure applications. Also, sensor damage may occur when used in acid gas environments such as hydrogen sulfide or hydrogen chloride.

##### 3.4.1.2 Zirconium Oxygen Sensors

Zirconium sensors operates under the same principles as the electrochemical sensors. They have an anode and cathode on either side of a Zirconium tube. The oxygen content is determined using an oxygen partial pressure differential, usually created by exposing one electrode to air (20.9% oxygen) while the other electrode is exposed to the sample gas.

These sensors can operate in high temperature environments and may be used directly at the sample point; however, the presence of particles may lead to a fouling of the sensor. They are not suitable for areas containing hydrocarbon solvent vapor, hydrogen or carbon monoxide, as a reaction with the sensor can occur leading to inaccurate oxygen levels results. They have a very fast response time and can operate at a very wide range of oxygen concentration levels (ppm to 100% $O_2$).

#### 3.4.1.3 Paramagnetic Oxygen Sensors

Paramagnetic sensors operate under the principle of the paramagnetic properties of oxygen. These sensors offer a fast response time and a longer lifespan than the electrochemical sensors. They require a sampling system when used on high temperature environments and for solvents applications special arrangements needs to be provided in order to prevent solvent condensation. The sensor is sensitive to vibration, shock and position. Background gases can also affect measurements accuracy.

The sensitivity of these oxygen analyzers may cause problems as they frequently need special preparation of the sample gas and always require regular maintenance and calibration programs. Alarm thresholds with a sufficient margin below the maximum permissible oxygen concentration should be specified.

In general, to select the most suited oxygen analyzer for a specific enclosure atmosphere or process, the characteristics of the analyzer as well as the following aspects need to be considered:

- Capable of resist process/storage conditions or include a sample conditioning system
- Active materials of the sensors to be compatible with the gases being sampled
- System response time
- Sensor sensitivity
- Suited for to the electrical hazard classification of the area or enclosure environment

## 4.0 REFERENCES

### 4.1 FM

Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*
*Data Sheet 7-32, Ignitable Liquids Operations*
*Data Sheet 7-35, Air Separation Processes*
*Data Sheet 7-43, Process Safety*
*Data Sheet 7-45, Safety Controls, Alarms and Interlocks*
*Data Sheet 9-0, Asset Integrity*
*Data Sheet 10-8, Operators*

## APPENDIX A GLOSSARY OF TERMS

**Inert gas:** In this data sheet, these are gases that do not present chemical reaction either with oxygen or the material to be inerted.

**Inerting:** The long-term maintenance of an inert atmosphere in an enclosed space that does not support any combustion, which means the oxygen level or fuel concentration is maintained at a value where combustion cannot occur.

**Limiting oxygen concentration (LOC):** The concentration of oxygen (oxidant) in a fuel-air (fuel-oxidant-diluent) mixture below which ignition cannot occur. This value is dependent on ambient pressure, temperature, and the test method used.

**Purging:** The act of moving an environment from one condition to another by introducing steam, air, or inert gas while displacing flammable vapor or gas to reduce the flammable concentration low enough to prevent ignition.

## APPENDIX B DOCUMENT REVISION HISTORY

**January 2022.** This document has been completely revised. Significant changes include the following:

A. Changed the title from “Inerting and Purging of Tanks, Process Vessels, and Equipment” to “Inerting and Purging Vessels and Equipment.”

B. Reorganized the document to provide a format that is consistent with other data sheets.

C. Added new recommendations and updated existing ones to align with current codes, standards, and industry practices. New recommendations include guidance on inerting operations for vessels and equipment, as well as monitoring and inerting systems.

D. Added information to support new recommendations (Section 3.0).

**July 2019.** Interim revision. The following changes were made:

A. Added recommendations on purging methods using air or steam.

B. Added recommendations on inerting tanks involving inhibiter monomers.

C. Updated guidance on inspection, testing, and maintenance.

D. Added support for recommendations for purging methods using air or steam (Section 3.0).

E. Clarified the definitions of “inerting” and “purging” (Appendix A).

**May 2000.** This document has been reorganized to provide a consistent format.

**December 1977.** New document issued.