SAFE INSTALLATION AND OPERATION OF PSA AND MEMBRANE OXYGEN AND NITROGEN GENERATORS

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NOTE—Technical changes from the previous edition are underlined.

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1 Introduction

As a part of the programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has adopted the original Compressed Gas Association (CGA) standard P-8.1. This standard is intended as an international harmonized standard for the use and application by members of CGA, EIGA, JIMGA and AIGA. This edition has the same content as the CGA edition except for editorial changes in formatting, units, spelling and references. References to U.S and Canadian regulatory requirements are replaced by references to international, national and local requirements and additional references are also made to applicable AIGA's documents.

Oxygen and nitrogen generators that use pressure swing adsorption (PSA) and membrane technologies, like many present day processes, have some degree of potential hazards that must be recognized and addressed. Common hazards associated with these generators are the asphyxiant properties of oxygen-deficient atmospheres and the ability of oxygen-enriched atmospheres to accelerate combustion. Other hazards include noise, electricity, rotating equipment, and gases under pressure.

Oxygen and nitrogen generator technology is not static; it has progressed rapidly over the last 15 years and continues to do so. Because a wide variety of plant process cycles, equipment, and operating conditions are in use, this publication includes some generalized statements and recommendations with which there may be diversity of opinion or practice. Users of this guide should recognize that it is presented with the understanding that it cannot take the place of sound engineering judgment, training, and experience. It does not constitute, and should not be construed to be, a code of rules or regulations.

2 Scope and purpose

2.1 Scope

This publication is a guide that applies to safety in the location, installation, operation, and maintenance of certain oxygen and nitrogen generators. Included are systems using PSA and membranes for nitrogen production, PSA and vacuum swing adsorption (VSA) for oxygen production, and catalyst-based oxygen removal systems for nitrogen purification. For systems using cryogenic technologies for the production of nitrogen, oxygen, or both (see CGA P-8, *Safe Practices Guide for Air Separation Plants* [1]).[1]

Emphasis has been placed on equipment and operational features that are peculiar to these system processes. Limited coverage has been given to plant equipment such as air compressors used in other industrial applications and for which safe practices in design, installation, and use have already been established elsewhere. While important supplemental equipment such as in-plant transfer piping is included, liquid backup for pipelines and cylinder filling facilities that are an adjunct to some oxygen and nitrogen generators are not covered. Also, coverage is not extended to equipment such as product transmission piping outside the generator boundaries.

While many references have been cited in this guide that give information relating to air separation plants, related equipment, and their products, the reference section is not intended to be all inclusive. Not all +, state, provincial, or local requirements, regulations, and ordinances are listed. Further, as this publication is not intended as a universal safe practices manual for specific design and safety features, it is important to refer to the operating manuals of the equipment supplier.

2.2 Purpose

This guide is intended to serve the interest of all who may be associated with oxygen and nitrogen generator installation and operations.

3 Definitions

For the purpose of this standard, the following definitions apply.

3.1 Asphyxiation

To become unconscious or die from the lack of oxygen.

3.2 Cryogenic liquid

Liquid material that is extremely cold at more than –130 °F (–90 °C).

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

NOTE—Oxygen, nitrogen, and hydrogen can be supplied in cryogenic liquid form.

3.3 Fail-safe

When a failure of a component of the system occurs, the resulting situation does not present a safety concern. One example is an isolation valve closing when the generator air or power supply fails.

3.4 Deoxo system

Catalytic-based system used with nitrogen generators to achieve a lower oxygen level than typically can be produced solely by the generator.

3.5 Double block and bleed

Piping/valving system used when two or more systems or parts of a system are required to be completely isolated from each other.

NOTE—It generally consists of two line-size blocking valves and a small bleed valve located between the blocking valves. The bleed valve vents any leakage from either blocking valve. When isolation is required, the blocking valves are closed and the bleed valve is opened.

3.6 Hot repairs

Use of a tool of high heat, for example a torch, that can be a safety hazard by itself; repairs made to a device that is in operation; or repairs made in a hazardous area when special safety precautions are necessary before, during, and after the work is performed.

NOTE—All hot repairs require care, safety supervision, and clear procedures. Use of a checklist or hazardous work permit is recommended.

3.7 Locked out

Condition where a device cannot be operated without a wilful, conscious action to do so.

NOTE—An example is when the electricity is turned off and cannot be regained without removing a protective device such as a padlock from the actuating device. Another example is a valve where the handle is removed and stored securely until such time it is safe to operate the valve.

3.8 Material safety data sheet (MSDS)

Document that describes a material and its associated hazards.

NOTE—The government mandates that generator suppliers provide MSDSs.

3.9 Membrane

Polymer material that acts like a filter to separate components such as nitrogen from oxygen in air.

3.10 Oxygen-deficient atmosphere/Nitrogen-enriched atmosphere

Air in which the oxygen concentration by volume is less than 19.5%; also known as nitrogen-rich atmosphere.

3.11 Oxygen-enriched atmosphere

Air in which the oxygen concentration by volume exceeds 23.5%; also known as oxygen-rich atmosphere.

3.12 Pressure relief device (PRD)

Device designed to protect a vessel or piping from achieving pressures higher or lower (vacuum) than its design to avoid the failure of the pipe or vessel.

NOTE—Because these devices can have significant flow when activated, the discharge should be directed to a safe area.

3.13 Pressure swing adsorption (PSA)

Family of generators that separates one gas from another by passing a feed gas over a bed of absorbent material at one pressure and cleaning the waste product off the adsorbent material at another pressure, hence the term pressure swing.

3.14 Safe area

Location where exhaust gases can be discharged safely causing no harm to personnel or property. A safe area is also a place where surrounding materials are compatible with the exhaust gas.

3.15 Safety permits

Procedural documents highlighting special safety considerations that are issued to allow work to commence in a specific location.

3.16 Vacuum swing adsorption (VSA)

Subset of the PSA family where one of the operating pressures is below atmospheric pressure (vacuum).

4 Health hazards

4.1 General

The operation of either oxygen or nitrogen generators can subject personnel to oxygen-deficient (asphyxiating) or oxygen-enriched (increased fire risk) atmospheres. Proper precautions, a basic knowledge of the behaviour of these gases, and wearing of personal protective equipment can minimize exposure to these hazards. Refer to the generator supplier's MSDSs for specific information on materials handled in oxygen and nitrogen generators.

Oxygen and nitrogen generators have both oxygen-deficient and oxygen-enriched atmosphere hazards as product or venting waste gas. Unlike gas cylinders or liquid oxygen/nitrogen storage that contains finite quantities of oxygen and nitrogen, generators produce a continuous product stream of oxygen and nitrogen. Over time this results in the significant accumulation of an oxygen-enriched or an oxygen-deficient atmosphere unless adequate ventilation is provided.

4.2 Cryogenic liquid hazards

In many cases, cryogenic liquid stored adjacent to the oxygen and nitrogen generators is used to back up or supplement the generator product supply. The handling of cryogenic liquid can cause unique hazards such as cryogenic “burns,” frostbite, and respiratory problems (see CGA P-12, *Safe Handling of Cryogenic Liquids*, for details [2]).

4.3 Nitrogen hazards

Nitrogen acts as a simple asphyxiant and, if present in sufficient quantity, can reduce the oxygen in the local atmosphere *and may cause death*.

The normal oxygen concentration in air is approximately 21% by volume. Air containing less than 19.5% or more than 23.5% oxygen constitutes a hazardous working environment The depletion of the quantity of oxygen in a given volume of air by displacement with an inert gas is a potential hazard to personnel.

When the oxygen content of air is reduced to approximately 15% or 16%, the rate of burning of combustible materials decreases significantly. The flame of ordinary combustible materials including those commonly used as fuel for heat or light is extinguished. This can be the first indication of an oxygen-deficient hazard. Somewhat below this concentration, an individual breathing the atmosphere is mentally incapable of diagnosing the situation as the symptoms of sleepiness, fatigue, lassitude, loss of coordination, errors in judgment, and confusion are masked by a state of euphoria, giving the victim a false sense of security and well being. See Table 1 for other typical symptoms of oxygen-deficient atmospheres.

WARNING: *Exposure to atmospheres containing 8% to10% or less of oxygen will bring about unconsciousness without warning and so quickly that the individuals cannot help or protect themselves. Lack of sufficient oxygen may cause serious injury or death.*

Nitrogen generators are very often operated inside closed buildings. Consequently, nitrogen leakage can result in an oxygen-deficient atmosphere within the building. Areas where it is possible to have this condition shall be well ventilated. Nitrogen vents should be piped outside of buildings or to a safe area (see 5.8). Where an oxygen-deficient atmosphere is possible, special precautions shall be taken such as installation of oxygen analyzers with alarms, ensuring a minimum number of air changes per hour, implementing special entry procedures, or a combination of these. Warning signs shall be posted at all entrances to alert personnel to the potential hazard of an oxygen-deficient atmosphere.

Table 1—Effects at various oxygen breathing levels

Percent oxygen at sea level (atmospheric pressure = 1.013 bar)	Effects
20.9	Normal
19.0	Some adverse physiological effects occur, but they are unnoticeable.
16.0	Increased pulse and breathing rate. Impaired thinking and attention. Reduced coordination.
14.0	Abnormal fatigue upon exertion. Emotional upset. Faulty coordination. Poor judgment.
12.5	Very poor judgment and coordination. Impaired respiration that may cause permanent heart damage. Nausea and vomiting.
<10	Inability to perform various movements. Loss of consciousness. Convulsions. Death.

NOTES

1 Humans vary considerably in their reaction to an oxygen-deficient atmosphere. It is, therefore, *not possible to predict exactly how people will react*. A general indication of what is liable to happen is given, but it should be understood that individual reactions may be different from those listed.

2 This table is adapted from ANSI Z88.2, *Respiratory Protection* [4].

3 These indications are for a healthy average person at rest. Factors such as individual health (for example, being a smoker), degree of physical exertion, and high altitudes can affect these symptoms and the oxygen levels at which they occur.

Nitrogen produced in generators is often used in areas remote from the generator itself. Therefore, it is important to recognize that accumulation of nitrogen in these use areas can also result in an oxygen-deficient atmosphere. For example, if nitrogen is used for instrument gas, control room atmosphere should be monitored for oxygen content since all pneumatic controllers bleed a certain amount of instrument gas.

It is important to note that the waste gas from oxygen generators contains significantly lower than 19.5% oxygen and without appropriate venting can create an oxygen-deficient atmosphere. Waste gas vents should be piped outside the building to safe areas.

CAUTION: *Be aware of the hazards of oxygen-deficient atmospheres.*

When there is any doubt of maintaining safe breathing atmosphere, self-contained breathing apparatus or approved air lines and masks should be used, particularly when personnel enter enclosed areas or vessels.

Oxygen monitor sensors should be placed in positions most likely to experience an oxygen-deficient atmosphere, and the alarm should be clearly discernible at the point of personnel entry.

Personnel working in or around oxygen-deficient atmospheres shall use the attendant system (sometimes referred to as the “buddy” system) for protected entry. It shall be recognized that the attendant is equally vulnerable to asphyxiation if entering the area to rescue the unconscious partner unless equipped with a portable air supply. The best protection is obtained by providing both the authorized entrant and the attendant with a portable supply of respirable air. Life lines are acceptable only if the area is free of obstructions and the attendant is capable of lifting the partner’s weight rapidly and without straining himself.

If an oxygen-deficient atmosphere is suspected or is known to exist by analysis, do not enter unless it is unavoidable and then only under the following conditions:

- Use the attendant system. Use more than one attendant if required to remove an authorized entrant in any emergency; and
- Provide both the authorized entrant and the attendant(s) with self-contained or air line breathing equipment.

See also CGA SB-2, *Oxygen-Deficient Atmospheres,* and CGA SB-15, *Avoiding Hazards in Confined Work Spaces during Maintenance, Construction and Similar Activities* and AIGA 008/11 *Hazards of inert gases and oxygen depletion* [5,6,26].

4.4 Oxygen hazards

Oxygen concentrations higher than 23.5% create greater fire hazards than normal air. Oxygen is not combustible, but it promotes very rapid combustion of flammable materials and some materials that are normally regarded as being relatively non-flammable. Although a source of ignition energy is always necessary in combination with flammable materials and oxygen, control or elimination of flammables is a precautionary step. Lubricating oils and other hydrocarbon materials can react violently with higher concentrations of oxygen, and the combination shall be avoided.

Personnel should not be exposed to an oxygen-enriched atmosphere because of increased risks of fire. As concentrations increase above 23.5% oxygen, ease of ignition of clothing increases dramatically. Once ignited by even a relatively weak ignition source such as a spark or cigarette, clothing can burst into flame and burn rapidly. Above approximately 60% oxygen, the nap on clothing and even body hair and oil are subject to flash fire that spreads rapidly over the entire exposed surface. See also AIGA 005/10 *Fire hazards of oxygen and oxygen enriched atmospheres* [27].

Oxygen generators are very often operated inside closed buildings. Consequently, oxygen leakage can result in an oxygen-enriched atmosphere within the building. Areas where it is possible to have this condition shall be well ventilated. Oxygen vents should be piped outside of buildings or to a safe area. Where an oxygen-enriched atmosphere is possible, warning signs shall be posted and special precautions shall be taken such as installation of analyzers with alarms, ensuring a minimum number of air changes per hour, implementing special entry procedures, or a combination of these.

Oxygen produced in generators is often used in areas remote from the generator itself. Therefore, it is important to recognize that accumulation of oxygen in these use areas can also result in an oxygen-enriched atmosphere.

It is important to note that the waste gas from nitrogen generators contains significantly higher than 23.5% oxygen and without appropriate venting can create an oxygen-enriched atmosphere. Waste gas should be vented outside the building or to a safe area.

CAUTION: Be aware of the hazards of oxygen-enriched atmospheres.

In the event persons inadvertently enter or are exposed to an oxygen-enriched atmosphere, they should leave as quickly as possible, avoid sources of ignition, and not smoke for at least 30 minutes. Opening clothing and slapping it helps to disperse trapped vapours.

4.5 Protective clothing

Proper clothing and special equipment can serve to reduce fire hazards when working with oxygen, but prevention of the hazard should be the primary objective.

Clothing should have minimum nap. A number of flame retardant materials are available such as NOMEX® for work clothing, but they can burn in high oxygen atmospheres. There is some advantage in these materials as most of them would be self extinguishing when removed to normal air atmospheres. All clothing should be clean and oil free. No means of ignition should be carried. Footwear should not have nails or exposed metallic protectors that could cause sparking.

5 General plant considerations

5.1 Site selection

Oxygen and nitrogen generator site selection should begin with a safety evaluation of the proposed location. Frequently, oxygen and nitrogen generators are located in or near other industrial/commercial areas. In all cases, the installation should conform to applicable industrial standards as well as all local and national regulations.

Since air is the raw material for these systems, its quality (type and degree of contamination with foreign materials such as hydrocarbons, acid gases, and particulate matter) is probably the major concern in selecting a suitable site. Trace quantities of contaminants in the compressed air, particularly oil, heavy hydrocarbons, and acid gases have a direct relationship to the safe operation and performance of oxygen and nitrogen generators. In an industrial/commercial area, some degree of contamination from industrial operations, chemical operations, or both should be expected. In general, the air compressor suction should not be near oxygen or hydrocarbon vent lines. Consult with the generator supplier to determine the acceptable levels of air contamination considered in the equipment design.

Site surveys should be made over a significant area around a proposed location. Attention should be given to the potential future development of the site in addition to the current use. Depending on the surroundings, it may be necessary to investigate sources of air contamination. If the evaluation of atmospheric conditions at the site is deemed unfavourable from a study of air contamination sources such as storage of other chemicals and wind data, then other sites should be considered if adaptive engineering modifications to the plant are not practical. If the investigation does not yield definitive results, more quantitative information should be obtained by monitoring the components in the air at the plant site over an extended period.

Potential fire or explosion hazards from nearby chemical storage or neighbouring industrial facilities should be investigated.

Sufficient space should be made available around the generator to allow for safe equipment maintenance and personnel traffic.

With oxygen and nitrogen generators, it is common practice to house the entire generator, or many of the key components, inside existing or new buildings. Storage of combustible materials should be avoided in buildings housing oxygen and nitrogen generators.

Personnel protection such as guard rails, platform gates, and ladder enclosures should be provided to prevent falls from elevated locations.

The generator location should be selected so a normal atmospheric oxygen content exists in all areas frequented by personnel while performing operational and maintenance activities. Consideration shall be given to the location of vents (see 5.8). Additionally, rotating equipment should not be exposed to oxygen-enriched atmospheres since it may have oil-lubricated parts.

Consideration should be given in building ventilation design to accommodate possible accumulation of product or waste gases. Adequate ventilation shall be provided to prevent localized oxygen-deficient or oxygen-rich atmospheres. As a guideline, the building should have a minimum of six air changes per hour.

The location of the oxygen compression equipment (if installed) should be given special consideration for the safety of operating and maintenance personnel. Generally this equipment and its associated piping should be as isolated as the layout permits to minimize personnel exposure and damage to nearby equipment in case of an incident. This equipment should be readily accessible for maintenance yet removed from the main personnel traffic pattern as far as possible (CGA G-4.6, *Oxygen Compressor Installation and Operation Guide* [7] and AIGA 048/08 *Reciprocating compressor for oxygen service* [28]).

Oxygen compressor fires typically produce high velocity oxygen jets containing molten-metal and metal oxides. Protective barriers should be used to isolate oxygen compression equipment to protect personnel and other equipment in case of a fire (see CGA G-4.6 [7]).

Requirements for emergency situations should be anticipated. Such things as emergency lighting, emergency trip stations, safe multiple exit routes, adequate fire protection, alarm systems, and equipment isolation valves are examples of safety features that should be considered for emergency situations.

Other general installation safety items that should be considered are the relative locations of adjacent equipment such as containers of flammable materials (e.g., oil), starting panels for oxygen compressors, oxygen gas meters, PRDs, liquid back-up systems, and automatic and manual control valves. Discuss these with the equipment supplier(s).

5.2 Materials of construction

Because the oxygen and nitrogen generators discussed in this publication operate at or about ambient temperature, carbon steel, copper, or both generally are used for interconnecting process piping, vessels, and pipelines. Where ambient conditions fall below –20° F (–29° C), precautions are necessary for the operation of carbon steel vessels and piping. Further, in cases when moisture is present, stainless steel or some other equally suitable metal should be considered. Due to the possibility of causing ignition by the impingement of high velocity particles, oxygen-enriched gas velocity should also be considered in the selection of materials [9]. Discuss all these issues with the generator supplier.

Non-metallic materials such as gaskets, valve packing, insulation, and lubricants shall be carefully checked to determine if they can be used for a particular application. All factors associated with their use such as temperature, pressure, and oxygen compatibility shall be considered in deciding if a material can be used without decreasing the safety integrity of an oxygen system.

Most non-metallic materials react with oxygen, some more than others. Since the ignition temperatures are relatively low for non-metallic materials, consult a qualified engineering source or the equipment supplier before using these materials. The vendor supplying the material may also be contacted for pertinent information.

5.3 Cleaning

An improperly cleaned and dried line in oxygen-enriched service is a hazardous condition. Under certain flow conditions, combustibles can be ignited by the impingement of particulates on metal.

All materials for use in or interconnected with systems should be suitably cleaned before the system is put into service. Mill scale, rust, dirt, weld slag, oils, greases, and other organic materials shall be removed. Fabrication and repair procedures should be controlled to minimize the presence of such contaminants and thereby simplify final cleaning procedures. See CGA G-4.1, *Cleaning Equipment for Oxygen Service* [8] and AIGA 012/04 *Cleaning of equipment for oxygen service* [29]. It is recommended that vendors responsible for cleaning for oxygen service be formally qualified to ensure proper procedures, handling, and packaging.

5.4 Electrical requirements

Oxygen and nitrogen generators are not considered hazardous for electrical equipment as defined by Article 500 of NFPA 70, *National Electrical Code* or CSA C22.1, *Canadian Electrical Code, Part I, Safety Standard for Electrical Installations* [9, 10]. Therefore, unless the generator is located in a classified area, general purpose or weatherproof types of electrical wiring and equipment are acceptable depending on whether the location is indoors or outdoors. Electrical equipment shall be grounded and all applicable provisions of NFPA 70, CSA C22.1, national and local codes, as applicable, should be followed.

In areas where an oxygen-rich atmosphere can be expected, electrical equipment with open or unprotected make-and-break contacts should be avoided. Generally the location of electrical equipment away from areas where an oxygen-rich atmosphere can occur eliminates potential hazards in these situations.

Some generators can have specific areas or equipment that necessitate special consideration such as a refrigeration system using a hydrocarbon refrigerant or one including a deoxo purification unit involving the use and handling of hydrogen. In these cases, the appropriate provisions of NFPA 70, CSA C22.1, national and local codes, as applicable, should be followed.

5.5 Fire protection

Typically, the primary fire protection for generators is an ample water supply. Depending on the generator size, an adequate number of fire hydrants, chemical-type fire extinguishers, hoses, or a combination of these should be strategically located close to the generator(s) so a fire can be approached from any direction in an emergency.

On oxygen systems, automatic isolation valves or generator shutdown are frequently used to isolate oxygen sources from feeding a fire.

5.6 Emergency shut-down system

A generator emergency shut-down system is advisable, especially for multi-plant installations. Larger generator(s) should be designed to permit shutting down a plant or plants from one or more locations, depending on local requirements, by tripping the appropriate switchgear to disconnect power.

5.7 Noise

The noise produced by compressors, vacuum blowers, and high gas velocities through piping, valves, pressure relief valves, and vents or bypasses shall be considered from the standpoint of potential hazard or nuisance to employees as well as to neighbouring areas. Noise abatement and use of personnel ear protection should be in accordance with 29 CRF 1910.95[3] or national and local regulations.

5.8 Venting

All vents should be directed away from personnel and equipment. Consideration shall be given to noise and the possible accumulation effect on the surrounding atmosphere. All product and waste gas vents together with pressure relief discharge ports should be vented to a safe area.

All vents that can contain hydrogen, whether operational or safety valves, should be piped outdoors, elevated to a minimum of 10 ft (3.1 m) above personal activity, and discharged vertically to a location with unobstructed circulation to prevent an explosion hazard.

All vents, whether operational or safety valves, should be piped to a safe area to prevent an asphyxiation or oxygen-enrichment hazard.

It is important to recognize that improper venting can provide a significant hazard even on very small oxygen and nitrogen units such as those used in laboratories or for home health care. As such units generally are not provided with remote venting capability, they should only be operated in well-ventilated areas where accumulation of either oxygen-deficient or oxygen-enriched atmospheres will not result.

Pressure relief valves should be located so their discharge cannot impinge on personnel or other equipment. They should not discharge into working or operating areas frequented by plant personnel.

PRDs located outside should have discharge ports protected from weather and water freezing. Vents shall be unrestricted.

Where PRDs are installed with a pipe extension, support should be provided to counter reaction forces when the device relieves.

Waste gases from oxygen and nitrogen generators are typically saturated with moisture. Hence, free drainage and protection against water freezing shall be considered.

Vents shall be routed and protected from damage by other nearby activities such as vehicular traffic.

5.9 Dusting

In PSA, VSA, deoxo systems, and dryers, a potential safety hazard can be created when sieve, catalyst, or drier desiccant material physically deteriorates over time. This deterioration is often referred to as dusting. Since these materials can be subjected to many cycles of pressure or temperature swing, dust particles can exit the containing vessel with the product gas. In addition to likely performance deterioration, dust can cause two types of safety concern, plugging and contamination. Plugging occurs when the dust slowly collects in downstream piping, valves, and instrument sample lines. In a safety valve, the setting of the lifting pressure can be artificially changed, preventing it from providing its pressure protection function. In a purity analysis instrument line, the product gas may not reach the analyzer, thereby giving a false reading. Contamination occurs when dust particles enter the manufactured product, rendering it unsafe or unfit for the intended service.

Dust also can be present in the waste gas vent and should be directed to a safe area. Even though the dust material may not be hazardous (consult the material's MSDS), it is a low level irritant to the nose and mouth and therefore should not be inhaled. The inlet to an air conditioner is an example of a location where discharge should be avoided.

Appropriate procedures to minimize the causes, recognize the occurrence, and resolve any problems associated with dusting should be thoroughly reviewed with the generator supplier.

5.10 Fluid discharge/solid disposal

PSA and membrane oxygen and nitrogen generators generally contain air compression and pre- or post conditioning systems that generate a water condensate stream requiring disposal. These condensate streams can contain small quantities of oil (biodegradable or non-biodegradable), glycol (if closed loop cooling is used), molecular sieve dust (carbon or zeolite), or catalyst dust containing trace quantities of heavy metals where deoxo systems are used. In all cases, provisions shall be made for the disposal of this condensate. In addition, provisions shall also be made for disposal of fluids used in the cleaning of the systems for oxygen or nitrogen service following maintenance. The provisions shall comply with current local, state, and federal environmental practices. The user should discuss the requirements with the equipment supplier and local permitting agencies to ensure proper procedures are followed.

It may be necessary to periodically dispose of solid materials as a result of normal maintenance procedures. Follow the directions on the MSDSs supplied with the system regarding material disposal requirements and confer with the supplier and local permitting agencies to ensure proper procedures are followed.

5.11 Hazard review

Before final decisions on site selection for a generator are made, a comprehensive safety review shall be conducted to identify potential hazards and to generate recommendations to reduce the probability of their occurrence, their consequences, or both. The review should be structured and systematic to examine all relevant parts of the equipment design including both normal and malfunctioning operations. Interaction with nearby and associated equipment and suitability for use of the product stream, particularly in case other-than-specified purity is generated, are also important factors to consider. A proper review procedure not only exposes potential hazards in the process but also identifies problems in the operations. Identification of these problems in the design stage can result in significant savings in capital and operating costs after the plant is installed.

The following is a set of general procedures for any hazard study:

a) State what the equipment item or process step was designed to accomplish. This is the design intention;

b) Use descriptive guide words (high, low, more, none, etc.) to identify deviations from the design intention (e.g., more pressure, reverse flow, no power, etc.)

   Typical parameters to consider in the analysis are operator error, testing, utility/power failure, static electricity, erosion, start-up, corrosion, shutdown, maintenance, commissioning, leak containment, vibration, sampling, state change (liquid to vapour), pipeline blockage, overflow in storage vessel, and nearby equipment failure;

c) For every deviation, examine possible causes and determine the potential consequences. This step may take the form of a “devil’s advocate—what if?” analysis in which the basic engineering design assumptions and the adequacy and reliability of each equipment item are questioned;

d) Identify safeguards for each of the possible consequences and list recommendations with assigned responsibilities to complete any required actions; and

e) Conduct a follow-up review before the initial operation of the equipment to verify that all previously identified concerns have been addressed and to uncover any additional hazards since the initial study.

6 Compressors

6.1 General

Many types of compressors are used with oxygen and nitrogen generators to compress air, product oxygen, or nitrogen. For the specific requirements for the location and installation of these machines, refer to the operating manuals provided by the machinery manufacturer and the oxygen and/or nitrogen generator supplier.

6.2 Special consideration for the compression of oxygen

In addition to the site considerations discussed in 5.1, the design and operation of oxygen compressors also require special knowledge and precautions. Monitoring systems are recommended that can detect the onset of dangerous operating conditions and take appropriate actions to mitigate their consequences. Parameters and the systems that may be monitored include discharge temperature, compressor vibration, operating pressures, seal system, lube oil system as well as surge control system. A high gas discharge temperature alarm and shut-down device should be located at the discharge of each compressor stage. Consult the system supplier's operating manual for monitoring system parameters. Special considerations should be given to personnel exposure, access and emergency response.

For more information on oxygen compression, refer to the following publications:

- CGA G-4.6, *Oxygen Compressor Installation and Operation Guide* [7];
- CGA G-4.1, *Cleaning Equipment for Oxygen Service* [9];
- CGA G-4.4, *Oxygen Pipeline Systems* (EIGA Doc 13/02) [11];
- CGA G-4, *Oxygen* [12];
- EIGA Doc 27/01, *Centrifugal compressors for oxygen service* [13];
- EIGA Doc 10/09, *Reciprocating compressors for oxygen service* [14]; and
- EIGA Doc 33/06, *Cleaning equipment for oxygen service* [15].

(AIGA publications are listed in the references)

6.3 Special consideration for the compression of nitrogen

Because of the inert nature of nitrogen, there is the possibility in the operation of a lubricated nitrogen compressor that some unoxidized carbonaceous material accumulates. It is possible for a fire or explosion to occur in these systems if the oxygen content of the gas increases substantially above what is normal for the unit. Therefore, it is important that product significantly out of specification that is high in oxygen not be allowed to enter the nitrogen generator product compressor.

Nitrogen produced by generators is usually very dry. Verify with the compressor supplier that use in dry nitrogen service poses no safety risks.

When the product nitrogen compressor is used in air service, it is important to clean it thoroughly of wear particles and any lubricant deposits to prevent a potential fire or explosion when air is first introduced.

For more information on nitrogen compression, refer to CGA P-8 and CGA P-9, *The Inert Gases: Argon, Nitrogen, and Helium* [1, 13].

7 Product storage

7.1 General

The hazards associated with the storage of oxygen, nitrogen, or combinations thereof depend on the conditions under which they are stored. Each storage system shall be suitable for the temperatures, pressures, and fluids involved.

7.2 Cryogenic liquid storage

Cryogenic liquid is stored in specially designed tanks ranging in size from several hundred to more than several million litres depending on the particular needs of the installation (see CGA P-8 and CGA P-12 [1, 2] and AIGA 030/06, *Storage of cryogenic air gases at users' premises,* AIGA 031/06, *Liquid oxygen, nitrogen and argon storage systems at production sites,* AIGA 027/06, *Cryogenic vaporization systems – prevention of brittle fracture of equipment and piping* [31,32,33]).

7.3 High pressure gas storage

Vessels used for high pressure gas storage should be installed, tested, and protected by relief device(s) in accordance with the *Boiler and Pressure Vessel Code* (ASME Code), Section VIII, Division 1 or equivalent international pressure vessel design codes, and should be internally inspected for cleanliness before being placed in service [14].

8 Plant piping

8.1 General

Piping systems should be suitable for the temperatures, pressures, and fluids involved. These should consider the applicability of ASME B31.3, *Process Piping*, as well as applicable national and local codes. Materials of construction shall be compatible and cleaned for the intended service (see 5.2 and 5.3).].. Materials of construction shall be compatible and cleaned for the intended service (see 5.2 and 5.3).

CGA G-4.4 and ASTM G-88, *Guide for Designing Systems for Oxygen Service*, are helpful guides for oxygen distribution systems [11, 17]. Also refer to AIGA 021/05, *Oxygen pipeline systems* [30].

8.2 Pressure relief devices

PRDs should be provided on any system that can be under- or over pressurized. Special consideration shall be given to over pressurization caused by trapping of cryogenic liquids. See CGA P-8 and P-12 [1, 2]. PRDs should be tested periodically to ensure functionality and set pressure.

8.3 Pressure reducing stations

A pressure reducing station is required whenever the produced and/or stored product pressure is higher than the use pressure.

A PRD should be installed on the low pressure side of the reducing station if regulator failure can allow pressure to exceed the user's maximum allowable working pressure (MAWP).

8.4 System isolation

Isolation capability should be included at reasonably accessible points or branches of the lines for test purposes, maintenance, and in the event of a system failure.

8.5 Aboveground piping

Lines installed above ground should be adequately supported. Expansion joints or loops should be used as necessary to compensate for expansion and contraction due to temperature changes. Piping systems should be adequately separated from external sources of heat, mechanical damage, and excessive vibration. Piping layouts should avoid tripping and/or bumping hazards.

8.6 Underground piping

Lines installed underground should not be of threaded or flanged construction. Lines should be adequately supported and the material under the line well drained. In all cases, enough flexibility should be provided by piping loops or expansion joints to compensate for the expansion and contraction due to temperature changes. Suitable external coating material should be used on the line to minimize ground-induced external corrosion. Where underground lines pass under roadways, they should be encased in suitable pipe sleeves that are vented to atmosphere. Where underground conditions warrant, cathodic protection should be used.

8.7 Insulation

Insulation should be used on equipment to protect personnel from either hot (>150 °F [66 °C]) or cold (< 32 °F [0 °C]) operating conditions. Insulation should be used to help prevent the freezing of moisture in process and instrument lines including those in compressed air service that can be exposed to cold ambient conditions. Insulation should be used to prevent condensation from cold process, instrument lines, or both that can cause slippery conditions.

9 Operations

9.1 General

A proper safety attitude and continuous emphasis on safe work procedures are the most important aspects of the operation of any oxygen or nitrogen generator. It is also important to recognize any new hazards that possibly can emerge because of the combined presence of the generator system and the user's other process systems.

The manufacturer of the generator and its related equipment should supply the user with complete operations and maintenance manuals. The user should adhere to these procedures at all times. These instructions should be kept current and retained with copies in a suitable place for easy reference.

For industrial units (not laboratory/health care), emergency response procedures for the site should be developed and understood by all operators and maintenance personnel.

9.2 Operations checklists/log sheets

Checklists should be available for the commissioning, start-up, and operation of the generator and all its components. These should be used at all times to ensure the generator is prepared and correctly set up for operation.

An operation log should be maintained to periodically monitor temperatures, pressures, vibrations, power, and capacity. Any deviation in operating values from normal conditions as stated in the manufacturer's manuals or instructions should be noted and appropriate correction made.

9.3 Procedures

Work on the equipment of an oxygen and nitrogen generator should be performed by qualified people. A safe work process that promotes critical analysis of the safety aspects and hazard potential of the job as it applies to all personnel should be established and all such procedures enforced.

Procedures should be developed to cover the proper response to anticipated emergency conditions that plant operators may have to face. Potential emergency conditions should include all possible plant upset conditions, mechanical malfunctions, and power or utility failures as well as environmental factors that can affect the plant safety. Emergency conditions that should be considered are:

- loss of power;
- loss of control air or power;
- severe mechanical failure such as failure of high pressure system;
- fire in a compressor;
- energy release;
- civil disturbance such as threat, riot, or other civil disobedience;
- severe weather conditions such as hurricane, tornado, or flood;
- adjacent industry incidents such as explosions, toxic chemical, or gas releases; and
- spills of lubricating oil or other chemicals used in oxygen and nitrogen generators.

In addition to coordinating company personnel and equipment to the best advantage, emergency procedures should include coordination with local emergency organizations (fire, police, and medical services).

9.4 Training

Initial start up of the generator and the training of operators should be done under the guidance of the generator supplier. Training can be accomplished by reference to the generator supplier's operating manuals, classroom work, supervised on-the-job training, or a combination of these.

Emphasis should be placed on the special skills required and the particular safety problems inherent in the operation of oxygen and nitrogen generators and the handling and storage of cryogenic liquids and high pressure gas if these are included with the system. First aid training should be given covering the health hazards noted in Section 4.

Training in the use of analytical equipment and supplementary breathing equipment should also be included. Periodic retraining should be scheduled and should include proper response to emergency conditions and review of operations that are infrequently performed.

9.5 Start-up

Before starting any oxygen or nitrogen generator, the user should thoroughly read and understand the operating manuals provided by the equipment supplier(s). They should provide a list of conditions to be checked before commencing the start-up.

If maintenance has been performed on the generator, confirm that the work has been completed, checked, and approved, and that all safety permits have been cleared and the equipment is ready to start. See AIGA 011/04 *Work Permit systems* [34].

When initially starting the system, it is critical that the users of the product are ready to accept the gas and have been trained in proper use and safety considerations.

After starting the generator, check that all operating conditions are normal before letting the unit run unattended. Recheck these conditions after the system has been running for several hours.

9.6 Shutdown

Refer to the manuals of the equipment supplier for specific shutdown procedures.

In shutting down an oxygen or nitrogen generator either deliberately, by power or utility failure, or by equipment malfunction, there is generally a built-in, fail-safe system of shutdown events. Numerous things can happen automatically. Valves close, vent valves open, equipment is shut down, and generally the plant should be in a safe standby condition. If there is no automatic system or if the automatic system fails, a listing of priority actions (such as product disposal and equipment venting) should be set up and the operators trained to perform the functions required with each individual type of generator.

9.7 Auto restart

Many oxygen and nitrogen generators today are operated remotely and include the capability to be started and/or stopped automatically or remotely. It is possible for the system to be in standby, idle but ready to restart automatically. It is especially important that these systems be locked out before the commencement of maintenance. This prevents any unintentional restart during maintenance. Signs that warn of the potential of automatic restart of the unit should be clearly posted around the equipment.

It is important that precautions be taken to ensure that equipment cannot be automatically started without the knowledge of personnel in the area around the equipment. Appropriate signs, warning lights, horns, procedures, etc., should be included to protect personnel. Different requirements apply depending on the service designation for the equipment. Specific recommendations are included in CGA P-8.6, *Unmanned Air Gas Plants—Design and Operation* (EIGA Doc 132/05) [21], (AIGA 028/06 [35].

9.8 Maintenance

9.8.1 Preventive maintenance programme

A regimented, thorough preventive maintenance programme is one crucial element of any safety programme. Good prevention is better than any cure. The generator maintenance programme should include periodic functional checks of the plant shut-down system to ensure that it performs as required in an emergency. The operation of pressure and temperature gauges, PRDs, automatic valves, controllers, and purity analyzers also should be checked periodically for accuracy.

9.8.2 Special construction and repair considerations

Particular care shall be taken when oxygen or nitrogen generators are operated during the construction, maintenance, or repair of other equipment adjacent to the generator. During these periods, the responsible personnel shall deal with all the normal aspects of safe oxygen or nitrogen generators as well as those special hazards that result from the combination of the two simultaneous operations.

Construction personnel should be familiarized with all safety regulations and made aware of all potential hazards.

One of the most significant hazards associated with PSA/VSA nitrogen and oxygen generators is exposure to atmospheres inside the adsorbent vessels while loading, removing, or inspecting the sieve material or its supports. Even when the generator is not in service, the sieve can adsorb or desorb nitrogen or oxygen due to changes in ambient temperature (see 10.2.2 and 11.2.2 for more details).

Oxygen and nitrogen generators are many times enclosed in cabinets that could be classified as a confined space. Consequently, oxygen-deficient or oxygen-enriched atmospheres can result inside the cabinets. Refer to Section 4 concerning the associated hazards and required precautions and to AIGA 011/04 *Work Permit systems* [34].

9.8.3 Repairs

When it is necessary to open piping or when performing hot repairs, process piping or vessels shall be depressurized, checked for purity, and purged with clean air until the concentration is between 19.5% and 23.5% oxygen. When an unsafe atmosphere can be introduced into the piping in which work is being performed, the lines shall be blanked or positively isolated. Removal of spool pieces or use of double block and bleed valves with the valves locked out and tagged are acceptable means. Frequent analyses of the atmosphere within the pipe are required. Care shall be taken when hot repairs are being made to pipes, vessels, etc., that could contain traces of chlorinated solvents or refrigerants since they can decompose with heat to form toxic gases.

Subject all new equipment as well as used equipment that may have become contaminated during maintenance to a good cleaning process. To ensure safe system operation, it is imperative that all contaminants are eliminated in process piping and components used for oxygen service. Inspect the cleaned piping and components and if evidence of contaminants is observed, clean the item again before installation or system restart.

Waste materials such as used lubrication oils, spent catalyst, adsorbent, and/or drier desiccant and other used repair materials should be disposed of properly. Refer to 5.10 and the appropriate MSDSs for details.

9.8.4 Pressure tests

Pressure testing of vessels and pipes should be done according to ASME Code, ASME B31.3, and ASME B31.1, *Power Piping* [14, 16, and 18] or in accordance to national or local requirements. Vessel repairs can require ASME Code recoding [14]. Even when that recoding is not required, vessels and piping should be leak tested before start-up.

10 PSA/VSA oxygen generators

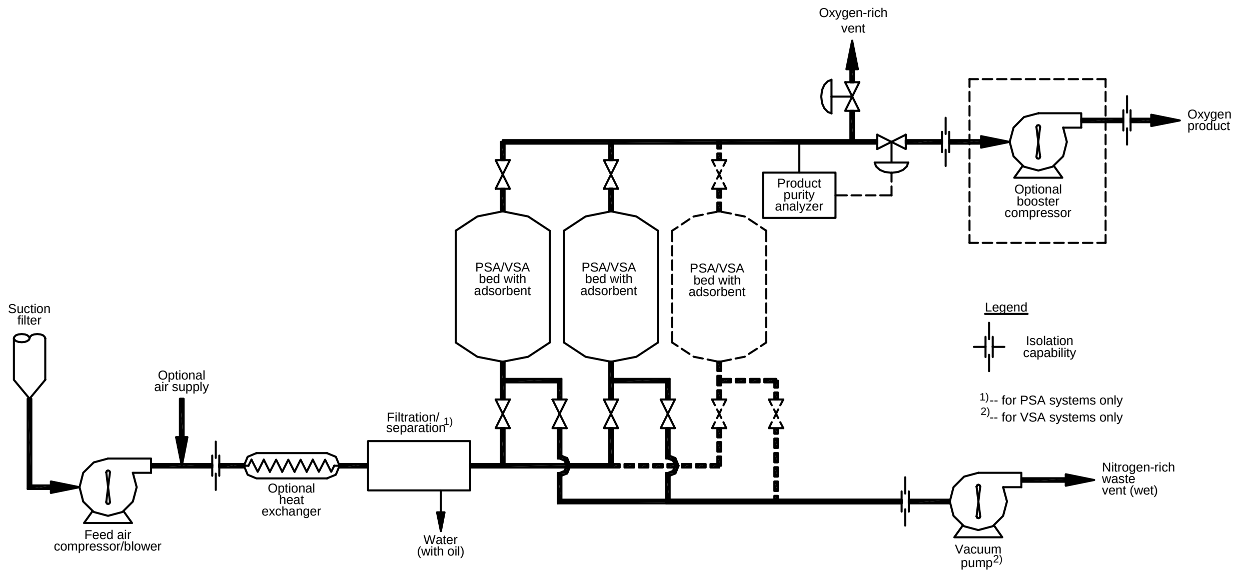
10.1 General

10.1.1 Purpose

PSA and VSA generators are used to produce gaseous oxygen at a specified purity, flow, and pressure from a compressed air source. This section provides a guide for the safe installation and operation of PSA or VSA systems. This section should be used in conjunction with Sections 4 through 9, which delineate general considerations and precautions pertinent to the safe installation, operation, and maintenance of any oxygen or nitrogen generator using air as the raw material. For specific design information, consult the operations manual provided with the system or contact the original equipment supplier.

10.1.2 System description

Typically two types of adsorption systems are offered today for oxygen production, PSA and VSA. A typical PSA/VSA oxygen generator flow diagram is shown in Figure 1. The fundamental technology involves the separation of oxygen from nitrogen by passing air through a bed of adsorbent, typically a zeolite. The adsorbent preferentially adsorbs nitrogen, water, and carbon dioxide and allows the bulk of the oxygen to pass through. After becoming saturated with nitrogen, the adsorbent bed is regenerated by reducing the pressure essentially to atmospheric in PSA systems and to vacuum conditions in VSA systems.



NOTE—The number of vessels can vary from one to four or more. The dotted vessel shown in Figure 1 is meant to indicate this variation in the number of vessels.

Figure 1—PSA/VSA oxygen generator flow diagram

Major equipment components include a feed air compression system, feed air pre-treatment equipment, and vessels containing adsorbent; process piping and valves; a vacuum pump (VSA systems only); a product oxygen compressor (when customer requirements are for pressures greater than the PSA or VSA system product pressure); process control systems; and other auxiliary components such as coolers, separators, storage receivers, cooling tower (if cooling water is required and not provided from a remote source), and instrument air systems.

Feed air compression systems for PSA oxygen generators typically are oil-flooded or oil-free screw compressors and, less frequently, oil-free reciprocating or centrifugal compressors. VSA systems generally use centrifugal blowers or rotary lobe blowers for the feed air. Vacuum pumps, which are often water-sealed rotary lobe blowers, are used to create a vacuum required for the regeneration of the adsorbent in VSAs. Pre-treatment of the air varies depending on the compressor and adsorbent used. For specific details, refer to the generator supplier's operating manuals.

All PSA and VSA systems include vessels containing adsorbent. Product purity is affected by controlling the operating pressure, temperature, and flow through the adsorber vessels.

10.2 Installation

10.2.1 General

General considerations that shall be understood to ensure safe installation and operation of PSA/VSA systems are detailed in Sections 4 through 9. The purpose of this section is to outline the hazards encountered specifically in PSA and VSA oxygen generators.

10.2.2 Site selection and installation

Indoor installations shall account for the possibility of an oxygen-enriched or oxygen-deficient atmosphere in the building. Adequate ventilation, oxygen concentration alarms, or both are recommended. All vents (including relief devices) shall be directed to a safe area (see 5.8).

PSA and VSA generators' mechanical equipment (e.g., compressors and vacuum blowers), valve switching, condensate drainage, and process flows can generate high levels of noise. Noise abatement and use of personnel ear protection should follow OSHA guidelines as well as local and national regulations as required [3].

In selecting the site for a PSA or VSA oxygen generator, there are air quality issues in addition to those covered in 5.1. The air should not contain elevated levels of impurities such as chlorine and chlorine compounds, ammonia, sulphur compounds, nitrogen oxides, and other acid gases that could damage the sieve. Consult with adsorbent and generator suppliers for specific details.

Sieve material is typically a non-hazardous synthetic zeolite. Users should refer to the supplier's MSDS to ensure safe handling during installation, operation, maintenance, and disposal. The sieve has a tendency to generate heat when exposed to water. Care shall be taken not to let the sieve get into the mouth or touch the eyes while handling. Sieve dust can irritate the nose, throat, eyes, lungs, and skin. Since some dust is present when working with the sieve, eye protection, dust masks, gloves, and clothing that cover the body should be worn.

One of the more hazardous operations in industrial PSA and VSA oxygen generators is exposure to the atmosphere inside the adsorbent vessels while loading, removing, or inspecting sieve beds. This exposure clearly occurs when entering the vessel, but also can occur when merely breathing the atmosphere near the vessel entry point. Even when the generator is not in operation, adsorbent material adsorbs or desorbs nitrogen due to changes in ambient temperature. This means that the atmosphere in a vessel can change rapidly to oxygen-enriched or oxygen-deficient. It is very important that dry, oil-free air be used to purge the vessel before and during vessel entry work. There shall be continuous monitoring of the atmosphere in the vessel while the work is being carried out, as well as having the appropriate external support systems, lines, etc. as outlined in 29 CFR Part 1910.146 or applicable national or local regulations. Oxygen compression systems are often associated with PSA/VSA oxygen generators. Oxygen compressor suppliers should be contacted if there are questions, concerns, or doubts. For further information regarding the safe compression of oxygen, refer to 6.2, CGA G-4.6, CGA G-4.1, CGA G-4.4, and CGA G-4 [7, 8, 11, and 12].

Figures 2 through 5 are examples of PSA/VSA oxygen generators.

10.3 Operations Hazards

10.3.1 Operating hazards

Before starting up any equipment, verify that a complete safety hazard review has been performed in accordance with 5.11. Read and thoroughly understand the operations manual provided by the generator supplier. Finally, confirm that the users of the oxygen-rich product are ready to accept the gas and have been trained in its use and the appropriate safety considerations.

Figure 2—Small oxygen PSA

Figure 3—Oxygen VSA

Figure 4—Three-bed oxygen PSA

Figure 5—Oxygen PSA medical unit

Improper disposal of the vent and waste gases, which are produced by the generator, can be extremely hazardous (see 5.8 for appropriate venting procedures).

All piping should be leak checked (soap test) immediately after the generator has been placed into operation, particularly if the generator is installed indoors. All leaks should be repaired before operating the generator to preclude the hazards of oxygen-enriched or oxygen-deficient atmospheres.

Many PSA/VSA oxygen generators today are operated remotely, which presents special hazards (see 9.7).

Product purity can vary depending on operating conditions. Varied levels of product purity may pose safety hazards depending on the end use. Proper and reliable analysis and consequent isolation by automated valves should be included. Before starting up, ensure that the analyzer is functioning properly and that it has been recently calibrated.

Valve systems cycle automatically and frequently during operation and care shall be taken to ensure that hands and tools are kept clear of these valves.

VSA generators may have water-sealed vacuum pumps. If so, the seal water shall be disposed of in a location certified to accept the water and any of its possible contaminants. See 5.10 for more details regarding process water handling and disposal.

In PSA and VSA oxygen generators, a potential safety hazard can be created when sieve material deteriorates over time. This deterioration is often referred to as dusting. As the sieve material is subject to many cycles of pressure-swing, small sieve particles can exit the adsorber bed with the product gas (see 5.9).

11 PSA nitrogen generators

11.1 General

11.1.1 Purpose

PSA nitrogen generators are used to produce gaseous nitrogen at a specified purity, flow, and pressure from a compressed air source. This section provides a guide for the safe installation and operation of a PSA nitrogen generator. This section should be used in conjunction with Sections 4 through 9, which delineate general considerations and precautions pertinent to the safe installation, operation, and maintenance of any oxygen or nitrogen generator using air as the raw material. For specific design information, consult the operations manual provided with the generator or contact the supplier.

11.1.2 System description

A typical PSA nitrogen generator flow diagram is shown in Figure 6. The fundamental technology involves the separation of nitrogen from oxygen by passing air through a bed of adsorbent, typically a carbon molecular sieve (CMS). Under pressure, the CMS material preferentially adsorbs oxygen and system operation moisture while passing nitrogen through the vessel. During generator operation, the CMS becomes saturated with oxygen. The CMS shall be systematically regenerated by desorbing the oxygen and moisture at low pressure.

Major equipment components include a feed air compression system; feed air pre-treatment equipment; vessels containing adsorbent; process piping and valves; a product nitrogen compressor (when customer requirements are for pressures greater than the PSA product pressure); process control systems; and other auxiliary components such as coolers, separators, storage receivers, and instrument air systems.

Figures 7 and 8 are examples of PSA nitrogen generators.

Feed air compression systems for PSA nitrogen generators are typically oil-flooded or oil-free screw compressors and, less frequently, oil-free reciprocating or centrifugal compressors. Pre-treatment of the air varies depending on the compressor and adsorbent used. For specific details, refer to the equipment manufacturer manuals.

Product purity is affected by adjusting the operating pressure, temperature, and flow through the adsorber vessels.

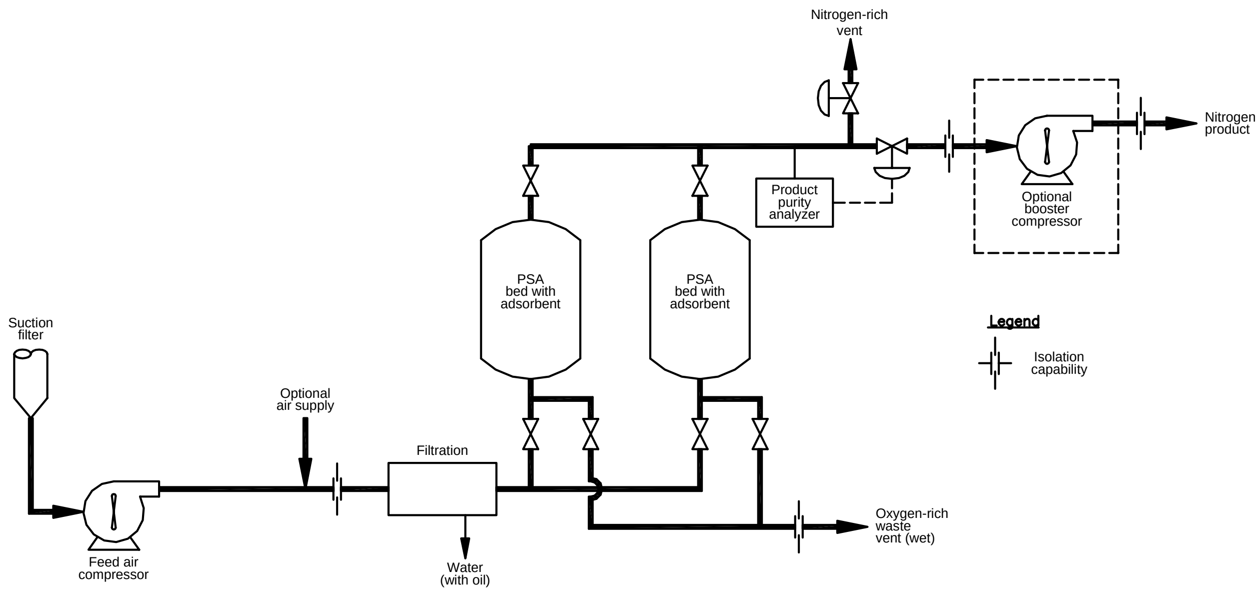


Figure 6—PSA nitrogen generator flow diagram

Figure 7—Small nitrogen generator

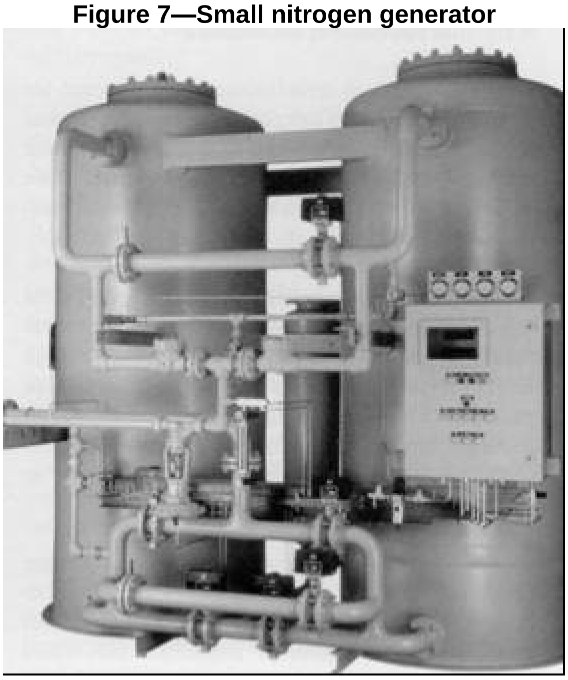


Figure 8—Nitrogen generator

11.2 Installation

11.2.1 General

General considerations that shall be understood to ensure safe installation and operation of PSA systems are detailed in Sections 4 through 9. The purpose of this section is to outline the hazards encountered specifically in PSA nitrogen generators.

11.2.2 Site selection and installation

Indoor installations shall account for the possibility of an oxygen-enriched or oxygen-deficient atmosphere in the building. Adequate ventilation, oxygen concentration alarms, or both are recommended. All vents (including relief devices) shall be directed to a safe area (see 5.8).

PSA systems' mechanical equipment (e.g., compressors), valve switching, condensate purging, and process flows can generate high levels of noise. Noise abatement and use of personnel ear protection should follow 29 CFR 1910.95 [3] or national and local regulations as required.

In selecting the site for a PSA nitrogen generator, there are air quality issues in addition to those covered in 5.1. The air should not contain elevated levels of impurities such as chlorine and chlorine compounds, ammonia sulphur compounds, nitrogen oxides, and other acid gases that could damage the CMS. Consult with the generator suppliers for specific details.

CMS is typically a non-hazardous carbon molecular sieve. Users should refer to the supplier's MSDS to ensure safe handling during installation, operation, maintenance, and disposal. Sieve dust can irritate the nose, throat, eyes, lungs, and skin. Since some dust is present when working with the sieve, eye protection, dust masks, gloves, and clothing that cover the body should be worn.

One of the more hazardous operations in industrial PSA nitrogen generators is exposure to the atmosphere inside the adsorbent vessels while loading, removing, or inspecting sieve beds. This exposure clearly occurs when entering the vessel, but also can occur when merely breathing the atmosphere near the vessel entry point. Even when the generator is not in operation, adsorbent material adsorbs or desorbs oxygen and/or nitrogen due to changes in ambient temperature. This means that the atmosphere in a vessel can change rapidly to oxygen-enriched or oxygen-deficient. It is very important that dry, oil-free air be used to purge the vessel before and during vessel entry work. There shall be continuous monitoring of the atmosphere in the vessel while the work is being carried out, as well as having the appropriate external support systems, lines, etc. as outlined in 29 CFR 1910.146 or, in applicable national or local regulations.

11.3 Operating hazards

Before starting up any equipment, verify that a complete safety hazard review has been performed in accordance with 5.11. Read and thoroughly understand the operations manual provided by the equipment supplier. Finally, confirm that the users of the nitrogen-rich product are ready to accept the gas and have been trained in its use and the appropriate safety considerations.

Improper disposal of the vent and waste gases produced by the generator can be extremely hazardous (see 5.8 for appropriate venting procedures).

All piping should be leak checked (soap test) immediately after the unit has been placed into operation, particularly if the system is installed indoors. All leaks should be repaired before operating the units to preclude the hazards of oxygen-enriched or oxygen-deficient atmospheres.

Many PSA nitrogen generators today are operated remotely which presents special hazards (see 9.7).Product purity can vary depending on operating conditions. This can pose certain safety hazards. Proper and reliable analysis and consequent isolation by automated valves should be included. Before starting up, ensure that the analyzer is functioning properly and that it has been recently calibrated.

Valve systems cycle automatically and frequently during operation and care shall be taken to ensure that hands and tools are kept clear of these valves.

In PSA systems, a potential safety hazard can be created when sieve material deteriorates over time. This deterioration is often referred to as dusting. As the sieve material is subject to many cycles of pressure-swing, small sieve particles can exit the adsorber bed with the product gas (see 5.9).

12 Membrane nitrogen generators

12.1 General

12.1.1 Purpose

Membrane nitrogen generators are used to produce gaseous nitrogen at a specified purity, flow, and pressure from a compressed air source. This section provides a guide for the safe installation and operation of membrane nitrogen generators. This section should be used in conjunction with Sections 4 through 9, which delineate general considerations and precautions pertinent to the safe installation, operation, and maintenance of any oxygen or nitrogen generator using air as the raw material. For specific design information, consult the operations manual provided with the system or contact the original equipment supplier.

12.1.2 System description

A typical membrane nitrogen generator flow diagram is shown in Figure 9. At the core of these systems is the membrane module. This module typically consists of thousands of small hollow fibres that are bound together on each end by tubesheets, formed into bundles, and contained within a protective outer shell. The compressed air feed stream can be introduced either on the shell or bore side of the membrane fibres. Since oxygen permeates more rapidly than nitrogen through the membrane wall, the feed air is separated into two gas streams. The first, the nitrogen product, is produced at essentially the compressed air pressure. The second, the waste stream, is enriched in oxygen and is at a low pressure, generally atmospheric.

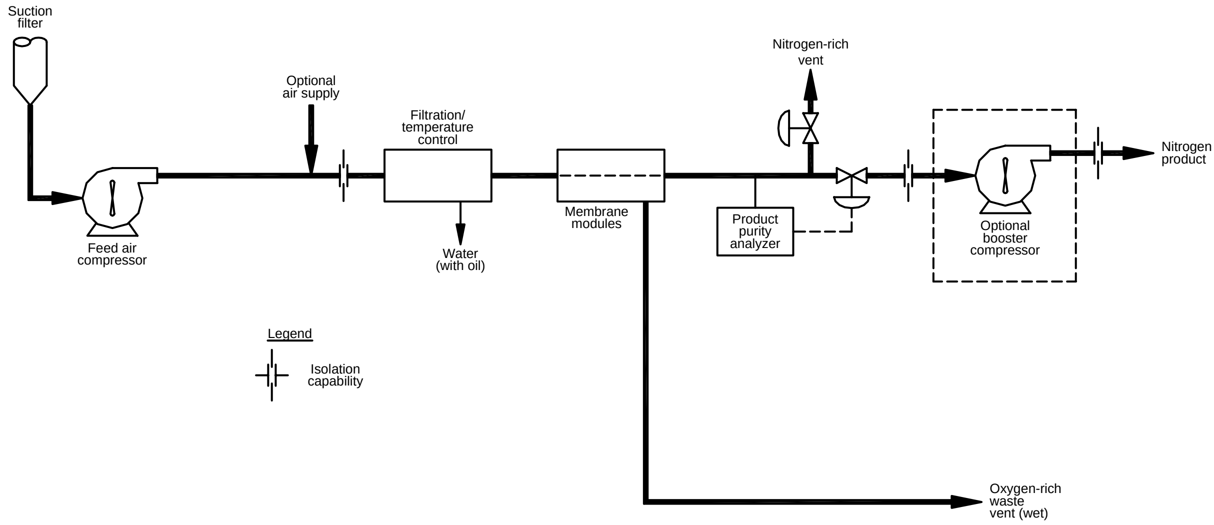


Figure 9—Membrane nitrogen flow diagram

Major equipment components include a feed air compression system; feed air pre-treatment equipment; membrane modules; process piping and valves; a product nitrogen compressor (when customer requirements are for pressures greater than the membrane product pressure); process control systems; and other auxiliary components such as separators, storage receivers, and instrument air systems.

The compressed air is generally treated to remove any condensed liquids, entrained mists, solid particulates, and sometimes vapour-phase contaminants before introduction into the membrane separator. The degree of clean up required depends on the particular contaminants present, the effects those contaminants have on the performance and lifetime of the membrane, and the final product purity requirements. Pre-treatment steps typically include cooling, filtration, and final temperature and/or pressure control.

After pre-treatment, the clean compressed air is fed to the membrane separator(s), which can be arranged alone or in multiple parallel or series banks.

Product purity is affected by controlling the operating pressure, temperature, and flow through the membrane module.

Figures 10 and 11 are examples of membrane nitrogen generators.

The typical air compressor used on membrane systems is an air-cooled, oil-flooded rotary screw machine. In some cases, specifically when trace amounts of compressor oil are not permitted in the final product, “oil-free” compressors including dry screw, non-lubed reciprocating, or centrifugal compressors can be required. An optional air receiver tank or water separator equipped with an automatic drain is sometimes installed downstream of the compressor.

Coalescing-type filters are generally used to effectively remove bulk oil and water droplets, entrained mist, and aerosols. In some cases, depending on the application and type of membrane being used, it is desirable to further purify the compressed air before it enters the membranes. Typical auxiliary treatment options include:

- air dryers (refrigeration or desiccant) to reduce water vapour content and prevent condensation;
- carbon adsorption filters to remove oil vapours;

– molecular sieve beds to remove undesirable chemical vapours; and
– air heaters to control membrane feed air supply temperature.

Figure 10—Nitrogen membrane

Figure 11—Small nitrogen membrane

12.2 Installation

12.2.1 General

General considerations that shall be understood to ensure safe installation and operation of membrane systems are detailed in Sections 4 through 9. The purpose of this section is to outline the hazards encountered specifically in membrane nitrogen generators.

12.2.2 Site selection and installation

Indoor installations shall account for the possibility of an oxygen-enriched or oxygen-deficient atmosphere in the building. Adequate ventilation, oxygen concentration alarms, or both are recommended. All vents (including relief devices) shall be directed to a safe area (see 5.8).

In selecting the site for a membrane nitrogen generator, there are air quality issues in addition to those covered in 5.1. The air should not contain elevated levels of impurities such as chlorine and chlorine compounds, ammonia, sulphur compounds, nitrogen oxides, other acid gases, condensable hydrocarbons, and particulate matter that could damage the membrane modules. Consult with the generator supplier for specific details.

12.3 Operating hazards

Before starting up any equipment, verify that a complete safety hazard review has been performed in accordance with 5.11. Read and thoroughly understand the operations manual provided by the equipment supplier. Finally, confirm that the users of the nitrogen-rich product are ready to accept the gas and have been trained in its use and the appropriate safety considerations.

Improper disposal of the vent and waste gases produced by the generator can be extremely hazardous (see 5.8 for appropriate venting procedures).

All piping should be leak checked (soap test) immediately after the unit has been placed into operation, particularly if the system is installed indoors. All leaks should be repaired before operating the units to preclude the hazards of oxygen-enriched or oxygen-deficient atmospheres.

Many membrane nitrogen generators today are operated remotely, which presents special hazards (see 9.7).

Product purity can vary depending on operating conditions. Varied levels of product purity may pose safety hazards depending on the end use. This can pose certain safety hazards. Proper and reliable analysis and consequent isolation by automated valves should be included. Before starting up, ensure that the analyzer is functioning properly and that it has been recently calibrated.

Some membrane nitrogen generators use a heater to raise and control the feed air temperature entering the membrane modules. If the heater is included, warnings and guards should be present to prevent personal injury during operation or maintenance.

In some installations, customer supplied compressed air which is remotely located from the membrane system will be utilized. Before startup, the quality of the air supply, including appropriate filtration selection and a regular maintenance plan to remove any condensable oil contained in the compressed air source, should be verified.

13 Oxygen removal (deoxo) systems for nitrogen systems

13.1 General

13.1.1 Purpose

Deoxo systems are used with PSA and membrane nitrogen generators to achieve a nitrogen purity level higher than that produced solely by the nitrogen generator. For example, 99% pure nitrogen produced by a PSA can be further treated to achieve parts-per-million (ppm) oxygen levels in the nitrogen via the addition of a deoxo system. This section provides a guide for the safe installation and operation of deoxo systems. This section should be used in conjunction with Sections 4 through 9, which delineate general considerations and precautions pertinent to the safe installation, operation, and maintenance of any oxygen or nitrogen generator using air as the raw material. For specific design information, consult the operations manual provided with the system or contact the original equipment supplier.

13.1.2 System description

The basis of the deoxo process is the reaction of oxygen and hydrogen over a catalyst bed typically of precious metal material. A typical deoxo flow diagram is shown in Figure 12. Hydrogen is added to the process to reduce the concentration of oxygen present in the product nitrogen stream of a nitrogen generator. This reaction is exothermic (gives off heat) and forms water. An aftercooler, separator, and dryer combine to remove the newly formed moisture and heat from the nitrogen stream. The hydrogen can be replaced with other fuels. These are not covered by this publication. Refer to the manufacturer's manuals for adequate safety precautions associated with any alternative fuel.

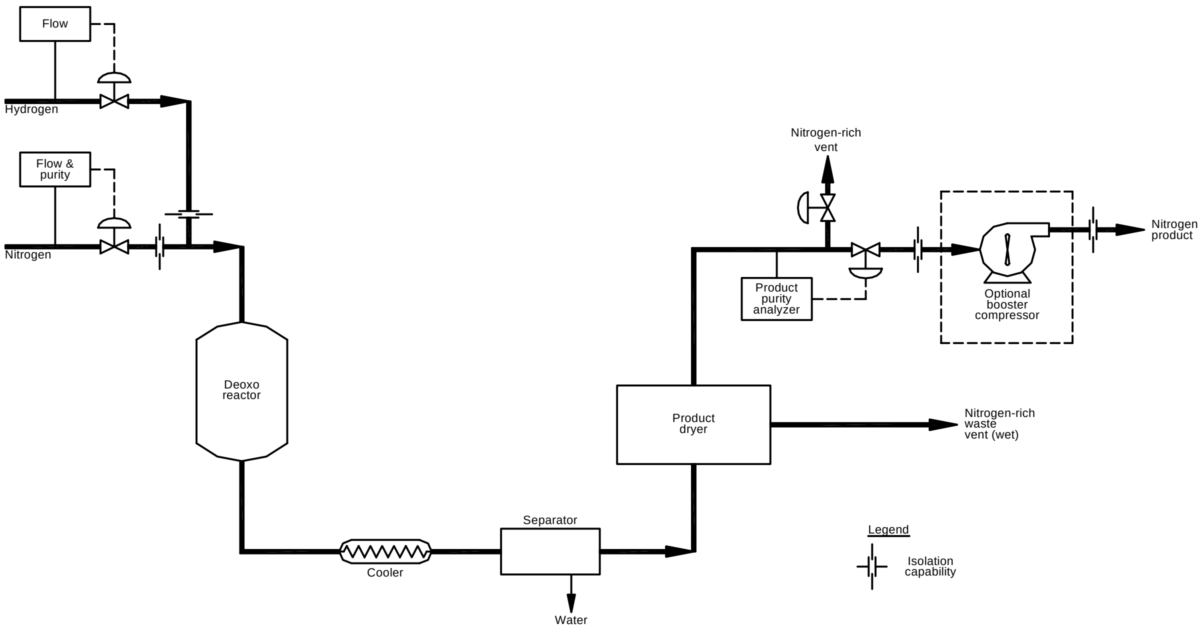


Figure 12—Deoxo flow diagram

The basic components of a deoxo system could include a gas mixing device, a deoxo reactor, an after-cooler, a separator, a dryer system, an after-filter, a set of controls complete with analyzers including excess hydrogen, and a hydrogen supply system.

Unlike most other sources of nitrogen, deoxo system nitrogen contains some level of hydrogen. The compatibility of hydrogen with the end use(s) for the nitrogen should be considered. For example, some aluminium processes cannot tolerate any hydrogen. In such applications, deoxo systems should not be used.

Figure 13 is an example of a deoxo system.

Figure 13—Deoxo system

13.2 Installation

13.2.1 General

General considerations that shall be understood to ensure safe installation and operation of deoxo systems are detailed in Sections 4 through 9. The purpose of this section is to outline the hazards encountered specifically in deoxo systems.

13.2.2 Site selection and installation

Indoor installations shall account for the possibility of oxygen-enriched, oxygen-deficient, or flammable hydrogen atmospheres in the building. Adequate ventilation, alarms, or both are recommended. All vents (including relief devices) shall be directed to a safe area (see 5.8).

Because a deoxo reactor and its aftercooler can run at elevated temperatures, e.g., 900 °F (482 °C), precautions should be taken to prevent purposeful or inadvertent direct contact by personnel. Insulation and protective barriers are effective when combined with a carefully selected location away from personnel traffic. For specific details, refer to the equipment manufacturer’s manuals.

Piping between the reactor and its aftercooler is also hot. Personnel protection insulation and special materials of construction should be provided. If operating temperatures of the nitrogen out of the cooler are above 150 °F (66 °C), personnel protection insulation should be provided (see 8.7).

Hydrogen either in liquid or gaseous form is highly flammable and requires special precautions. Hydrogen is easily ignited, even by static electricity. Hydrogen-fuelled flames are nearly invisible in daylight. To lessen the probability of hydrogen leakage, welded pipe construction should be used in place of screwed connections. Special valves and specific materials of construction for hydrogen service should be used. Because hydrogen mixed with air provides an explosive atmosphere, sources of ignition in close proximity to the hydrogen sources should be eliminated. For example, electric equipment in the area where hydrogen is stored should be explosion proof in accordance with NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, and NFPA 50B, *Standard for Liquid Hydrogen Systems at Consumer Sites* [19, 20] or equivalent international codes. No open flames should ever be allowed.

All vents possibly containing hydrogen should be treated in accordance with recommendations cited in CGA
G-5, *Hydrogen* and G-5.5, *Hydrogen Vent Systems* [21, 22]. Vents containing nitrogen pose an asphyxiation hazard and should be vented to a safe area (see 5.8).

13.3 Operations Hazards

Before starting up any equipment, verify that a complete safety hazard review has been performed in accordance with 5.11. Read and thoroughly understand the operations manual provided by the equipment supplier.

Improper disposal of the vent and waste gases produced by the deoxo system can be extremely hazardous (see 5.8 for appropriate venting procedures).

All piping should be leak checked (soap test) immediately after the unit has been placed into operation, particularly if the system is installed indoors. All leaks should be repaired before operating the units to preclude the hazards of oxygen-enriched or oxygen-deficient atmospheres. Further, hydrogen leaks can also lead to serious fire and explosion risks.

The deoxo product purity can vary depending on operating conditions. Further, nitrogen generators upstream of the deoxo system can produce gas with variable oxygen concentration based on both throughput (operating flow rate) and ambient temperature and pressure changes. The hydrogen ratio control shall be adequately ranged and respond fast enough to the expected inlet gas purity composition range and rate of change. The operator shall be aware of the oxygen and hydrogen concentration limitations established by the equipment manufacturer to safely operate the deoxo system. If any limit is exceeded, the deoxo system shall be shut down, and the cause for the excursion determined and corrected before restarting. Also proper and reliable analysis of the deoxo product nitrogen and consequent isolation by automated valves should be included since a product rich in oxygen can pose a hazardous condition for the downstream application. Before starting up, ensure that all analyzers are functioning properly and have been recently calibrated.

Too much oxygen in the feed nitrogen gas to the deoxo system can cause an unsafe condition. The purity of the nitrogen from PSA and membrane systems is a function of its throughput. For example, assume a PSA is designed to produce 99% nitrogen at a certain design flow rate. When the PSA is only producing one-third of this flow rate, the nitrogen purity is higher than 99%. Conversely, if the flow rate exceeds the design or the sieve or membrane is under performing, the oxygen concentration rises. With adequate hydrogen feed, the reactor temperature reflects the concentration of the incoming oxygen. If low-purity control is not provided on the nitrogen or is not functioning properly, any abrupt oxygen increase causes a steep rise in deoxo temperature, resulting in an unsafe condition. This could include vessel failure if the design limits of the reactor are exceeded. The temperature rise is approximately 30 ºF (17 ºC) for every 0.1% oxygen. Refer to the equipment manufacturer’s manual for inlet oxygen concentration limits, typically 3% or less.

Understanding the control concept of the deoxo system is critical to safe and efficient operation. Care shall be exercised to ensure a safe and efficient operation with varying amounts of hydrogen and/or oxygen present in the system. Typically, the quantity of hydrogen is determined by monitoring the flow and oxygen concentration of the deoxo feed nitrogen gas. Hydrogen is then added as a ratio of the total oxygen. Fine tuning is accomplished by monitoring the excess hydrogen concentration of the system. Refer to the deoxo system supplier’s operating manual for a more comprehensive description.

Maintaining an acceptable reactor temperature is an important safety operation. Assuming all oxygen is being removed by the deoxo system, the reactor temperature is directly proportional to the inlet oxygen concentration. This concentration shall be limited within temperature limitations of the equipment and piping. Refer to exact oxygen concentration limitations contained in the deoxo system supplier’s recommendations.

Too little or too much hydrogen in the deoxo exit gas can cause an unsafe condition. To ensure proper nitrogen purities are achieved, excess hydrogen shall be present in the nitrogen product, usually controlled in the tenths of a percent hydrogen concentration. Hydrogen levels above 4% contribute to a flammability or explosion hazard if the mixture leaks or is vented to the atmosphere. As this is a normal practice during shut-down venting, special precautions are needed for the design and location of hydrogen-containing vents. Refer also to 5.8.

Because hydrogen is injected into nitrogen piping, precautions should be taken to prevent hydrogen backflow into the nitrogen system that may not be designed with adequate hydrogen-related safety considerations. Shut-down periods are prime candidates for such backflow to occur. On a shutdown, a double block and bleed valve arrangement is a positive means of backflow prevention.

The source of hydrogen is usually gas, vaporized liquid or dissociated ammonia. The installer and/or user should be familiar with safe precautions specific to each. Refer to CGA G-5 for the handling of hydrogen [21].

Desiccant type dryers typically are used when moisture is unacceptable in the nitrogen product. A reactivation heater can be used to remove accumulated moisture from a saturated dryer bed. The reactivation heater should not be allowed to function unless a minimum purge gas flow has been established. This is to avoid reaching too high a temperature in the bed. Refer to the equipment manufacturer's recommendations regarding the exact limitations. On auto-start systems, a high sheath temperature shutdown should be provided for the heater. Dryer vent discharges are nitrogen and should be vented to a safe area (see 5.8).

Before starting or restarting the deoxo system, all equipment and controls should be calibrated and verified as operating properly. Before introducing hydrogen, establish the proper flow, pressure, and purity in accordance with the manufacturer's instructions. Once hydrogen has been introduced, do not override any safety interlock for any reason.

For planned or unplanned shutdowns, all vents should be automated to discharge to a safe location. A hydrogen valve should interlock to close the hydrogen supply when the system is stopped. If the unit is scheduled to remain down for a prolonged period, the hydrogen source should be manually isolated and tagged as out of service. Double block and bleed valve systems, blind flanges, and pipe-spool removal are all means of providing positive shutoff. For other shutdown information, refer to 9.6.

Before beginning maintenance activities, all lines and equipment should be purged to remove any hydrogen. During maintenance, periodic leak checking of piping and instrumentation prevents small leaks from contaminating areas surrounding the deoxo system with potentially explosive air-hydrogen mixtures.

In a deoxo system, a potential safety hazard can be created when catalyst and/or drier material deteriorates over time. This deterioration is often referred to as dusting. As the catalyst and/or drier material is subjected to many cycles of pressure-swing, small particles can exit the adsorber bed with the product gas. For further information, refer to 5.9.

14 References

Unless otherwise specified, the latest edition shall apply.

[1] CGA P-8, *Safe Practices Guide for Air Separation Plants,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[2] CGA P-12, *Safe Handling of Cryogenic Liquids*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[3] *Code of Federal Regulations*, Title 29 CFR (Labor), Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. www.access.gpo.gov

[4] ANSI Z88.2, *Respiratory Protection*, American National Standards Institute, 25 West 43rd St., New York, NY 10036. www.ansi.org

[5] CGA SB-2, *Oxygen-Deficient Atmospheres,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[6] CGA SB-15, *Avoiding Hazards in Confined Work Spaces During Maintenance, Construction, and Similar Activities*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[7] CGA G-4.6, *Oxygen Compressor Installation and Operation Guide*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[8] CGA G-4.1, *Cleaning Equipment for Oxygen Service*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[9] NFPA 70, *National Electrical Code*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169. www.nfpa.org

[10] CSA C22.1, *Canadian Electrical Code, Part I, Safety Standard for Electrical Installations,* Canadian Standards Association, 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada. www.csa.ca

[11] CGA G-4.4, *Oxygen Pipeline Systems (EIGA Doc 13/02)*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[12] CGA G-4, *Oxygen,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[13] EIGA Doc 27/01, *Centrifugal Compressors for Oxygen Service*, European Industrial Gases Association, Avenue des Arts 3-5, B-1210 Brussels, Belgium. www.eiga.org

[14] EIGA Doc 10/09, *Reciprocating Compressor for Oxygen Service*, European Industrial Gases Association, Avenue des Arts 3-5, B-1210 Brussels, Belgium. www.eiga.org

[15] EIGA Doc 33/06, *Cleaning of Equipment for Oxygen Service Guideline*, European Industrial Gases Association, Avenue des Arts 3-5, B-1210 Brussels, Belgium. www.eiga.org

[16] CGA P-9, *The Inert Gases: Argon, Nitrogen, and Helium,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[17] ASME *Boiler and Pressure Vessel Code,* Section VIII, Div 1, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[18] CSA B51, *Boiler, Pressure Vessel, and Pressure Piping Code,* Canadian Standards Association, 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada. www.csa.ca

[19] ASME B31.3, *Process Piping*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[20] ASTM G-88-90, *Standard Guide for Designing Systems for Oxygen Service*, ASTM International, 100 Bar Harbor Dr., West Conshohocken, PA 19428. www.astm.org

[21] CGA P-8.6, *Unmanned Air Gas Plants—Design and Operation (EIGA Doc 132/05)*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[22] ASME B31.1, *Power Piping*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[23] NFPA 55, *Standard for Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and T*anks, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[24] CGA G-5, *Hydrogen,* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[25] CGA G-5.5, *Hydrogen Vent Systems*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[26] AIGA 008/11, *Hazards of inert gases and oxygen depletion,* Asia Industrial Gases Association, www.asiaiga.org

[27] AIGA 005/10, *Fire hazards of oxygen and oxygen enriched atmospheres,* Asia Industrial Gases Association, www.asiaiga.org

[28] AIGA 048/08, *Reciprocating compressor for oxygen service,* Asia Industrial Gases Association, www.asiaiga.org

[29] AIGA 012/04, *Cleaning of equipment for oxygen service,* Asia Industrial Gases Association, www.asiaiga.org

[30] AIGA 021/05, *Oxygen pipeline systems,* Asia Industrial Gases Association, www.asiaiga.org

[31] AIGA 030/06, *Storage of cryogenic air gases at users' premises,* Asia Industrial Gases Association, www.asiaiga.org

[32] AIGA 031/06, *Liquid oxygen, nitrogen and argon storage systems at production sites,* Asia Industrial Gases Association, www.asiaiga.org

[33] AIGA 027/06, *Cryogenic vaporization systems – prevention of brittle fracture of equipment and piping,* Asia Industrial Gases Association, www.asiaiga.org

[34] AIGA 011/04. *Work Permit systems,* Asia Industrial Gases Association, www.asiaiga.org

[35] AIGA 028/06 *Unmanned Air Gas plant – Design & Operation*, Asia Industrial Gases Association, www.asiaiga.org