SAFE PRACTICES FOR STORAGE AND HANDLING OF NITROUS OXIDE

Doc 176/19

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) publication EIGA Doc 176 *Safe Practices for the Storage and Handling of Nitrous Oxide* has been used as the basis of an internationally harmonised gas association's publication on this subject.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), EIGA, and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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Note: Technical changes from the previous edition are underlined

1. Introduction

Nitrous oxide (N_2O) has been produced and distributed by the industrial gases industry for many years. It is mainly used for medical purposes (anaesthesia), food packaging, and electronic industries.

Incidents such as violent decomposition of nitrous oxide and the rupture of nitrous oxide tanks have occurred at production, storage, and distribution facilities. In addition, nitrous oxide gas in elevated concentrations can cause health effects in personnel, which shall be prevented.

This publication describes the properties and hazards of nitrous oxide. On this basis, the principles and relevant details of safe storage and distribution of nitrous oxide are considered. Most severe incidents have been caused by insufficient understanding of the properties of nitrous oxide.

Regulatory requirements for medical applications shall also be followed.

2. Scope

This publication addresses the safe use in the industrial and medical gases industry for the design, engineering, construction, and operation of nitrous oxide, storage, and supply installations. The design and installation requirements and recommendations included in this publication apply only to installations begun after the publication date. Some design and installation requirements shall be considered for existing installations where specified in this publication. These requirements shall be completed within 2 years of publication of this standard.

Operational requirements and recommendations should be considered for existing installations. This publication does not cover the manufacturing of nitrous oxide or quality control and analysis procedures. Refer to EIGA Doc 175, *Safe Practices for the Production of Nitrous Oxide from Ammonium Nitrate* [1]. [1]

3. Definitions

For the purposes of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

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

3.2 Technical definitions

3.2.1 Authorized person

Trained and qualified person approved or assigned to perform specific types of duties or to be at a specific location.

3.2.2 Bundle (of cylinders)

Assembly of cylinders that are fastened together and are interconnected by a manifold and transported as a unit.

3.2.3 Cryogenic receptacle

Transportable thermally insulated pressure receptacle for refrigerated liquid gas of a capacity of not more than 1000 L (264 gal).

3.2.4 Cylinder

Transportable pressure receptacle of a water capacity not exceeding 150 L (40 gal).

3.2.5 Decomposition

Separation of a chemical compound into smaller elements. Nitrous oxide separates into components in an exothermic reaction that can be accelerated by changes in pressure, temperature, energy inputs, presence of catalyser, or impurities.

3.2.6 Filling degree

Percentage of the volume of liquefied gas to the volume of water at 15 °C (59 °F) that would completely fill a pressure receptacle or tank.

3.2.7 Filling ratio

Ratio of the mass of gas to the mass of water at 15 °C (59 °F) that would completely fill a pressure receptacle or tank.

3.2.8 Liquefied gas

Gas that when packaged under pressure for carriage is partially liquid at temperatures above –50 °C (–58°F).

3.2.9 Maximum allowable working pressure (MAWP)

Maximum effective gauge pressure permissible at the top of the shell of a loaded tank in its operating position including the highest effective pressure during filling and discharge.

3.2.10 Minimum design metal temperature (MDMT)

Lowest temperature at which a pressure receptacle is designed to safely operate at maximum allowable working pressure (MAWP).

3.2.11 Net positive suction head (NPSH)

Total head of liquid at the inlet to a pump above the equilibrium pressure head.

3.2.12 Oxipotential

Dimensionless number that indicates the oxidizing power of a gas compared to pure oxygen. The oxipotential value of 100% oxygen is 1.0 and air is 0.21.

3.2.13 Pressure

Bar (psi) shall indicate gauge pressure unless otherwise noted – i.e., bar, abs (psia) for absolute pressure and bar, dif (psid) for differential pressure.

3.2.14 Pressure receptacle

Collective term that includes cryogenic receptacles, cylinders, and bundles.

3.2.15 Knowledgeable nitrous oxide technician

Person by reason of education, training, and experience that knows the properties of nitrous oxide; is familiar with the equipment used to store, transfer, and use nitrous oxide; and understands the precautions necessary to safely use nitrous oxide equipment.

3.2.16 Refrigerated liquid gas

Gas that when packaged for carriage is made partially liquid because of its low temperature.

3.2.17 Stationary tank

Thermally insulated or non-insulated tank at a stationary place that can be filled with liquefied gas or refrigerated liquid gas under pressure for storage purposes.

3.2.18 Tank

Collective term that includes stationary tanks and transport tanks.

3.2.19 Transport tank

Transportable thermally insulated tank for refrigerated liquid gas having a capacity of more than 450 L (118 gal).

4. Properties and hazards

For nitrous oxide identification and properties, see Tables 1, 2, and 3.

Table 1—Identification of nitrous oxide

Chemical formula	N_2O
Synonyms	Laughing gas, dinitrogen monoxide
CAS registry number	10024-97-2
EC number	233-032-0
UN number and shipping name	UN 1070, Nitrous oxide [1)] UN 2201, Nitrous oxide, refrigerated liquid

1) UN 1070, Nitrous oxide is a liquefied gas. According to the United Nations (UN) *Model Regulations for the Transport of Dangerous Goods*, it is a high pressure liquefied gas because its critical temperature is between –50 °C and 65 °C (–58 °F and 149 °F) [2].

4.1 Physical properties and hazards

Table 2—Properties of nitrous oxide

Colour, odour, and taste:	Colourless, sweet odour, tasteless
Characteristics:	Non-flammable Supports combustion Oxidizing gas Anaesthetic Non-corrosive Does not form an acid in water

	SI units	U.S. units
Molecular weight	44.01	
Density of gas at reference conditions 21.1 °C (70 °F) and 101.325 kPa, abs (14.696 psia) 15 °C (59 °F) and 14.696 psia (101.325 kPa, abs)	 1.947 kg/m^3 1.88 kg/m^3	 0.1146 lb/ft^3 0.1172 lb/ft^3
Density of gas, at –0 °C (32 °F) and 14.696 psia, (101.325 kPa, abs)	1.977 kg/m^3	0. 123 lb/ft^3
Specific gravity of gas compared to air	1.53	
Density of liquid, at 1 atmosphere pressure (101.325 kPa)	1227 kg/m^3	76.6 lb/ft^3
Critical temperature	36.5 °C	97.7 °F
Critical pressure	71.45 bar	1039 psi
Boiling point at 1 atmosphere pressure (1.013 bar)	–88.3 °C	–127 °F
Melting point of solid at 1 atmosphere (1.013 bar)	–90.8 °C	–131.5 °F
Heat of fusion at melting point	148.9 kJ/kg	64 Btu/lb
Heat of vaporization at normal boiling point	376.3 kJ/kg	161.8 Btu/lb
Triple point pressure	8.78 bar, abs	12.7 psia
Triple point temperature	–90.8 °C	–131.5 °F
Heat capacity, C_p, of gas at 59 °F (15 °C) and 1 atm (101.325 kPa)	0.866 kJ/kg °C	0.207 Btu/lb °F
Heat capacity, C_v, of gas at 59 °F (15 °C) and 1 atm (101.325 kPa)	0.665 kJ/kg °C	0.159 Btu/lb °F
Solubility in water at 25 °C (77 °F) at atmospheric pressure	0.59 v/v	

Table 3—Properties of saturated liquid nitrous oxide [3, 4]

Temperature °F	Temperature °C	Vapour pressure psia	Vapour pressure bar, abs	Liquid density lb/gal	Liquid density kg/L
–131.5	–90.82	12.73	0.878		
–127.2	–88.47	14.69	1.013	10.20	1.2228
–110	–78.89	26	1.793	10.36	1.241
–90	–67.78	46	3.172	10.02	1.201
–70	–56.67	73.98	5.102	9.69	1.161
–50	–45.56	111.97	7.722	9.26	1.110
–30	–34.44	166.95	11.514	8.95	1.073
–10	–23.33	239.93	16.547	8.65	1.036
10	–12.22	334.9	23.097	8.18	0.980
32	0	453.7	31.290	7.54	0.904
50	10	589.85	40.679	6.99	0.838
59	15	654.24	45.120	6.83	0.818
70	21.11	759.8	52.400	6.22	0.745
97.5	36.41	1050.5	72.450	3.86	0.452

4.1.1 Specific hazards

Personnel handling nitrous oxide should be trained in the hazards associated with this product. There are several conditions in which danger to personnel and equipment can exist. The following subsections describe these conditions and offers procedures and guidelines to prevent dangerous conditions from developing.

4.1.1.1 Low temperature effects on materials

The low temperature effect of nitrous oxide liquid and vapour on the materials in the system can create a hazard. At atmospheric pressure, the temperature of liquid nitrous oxide is –88 °C (–127 °F) and many materials used in hose and piping systems can become brittle and fail if highly stressed. Materials used in the construction of nitrous oxide supply systems shall be compatible with nitrous oxide and the temperature and pressure conditions encountered.

Piping systems subject to operating temperatures less than ambient can contract. Allowances shall be made in piping and support systems to compensate for these changes in dimensions. Copper tubing, which is commonly used, shrinks approximately 2.5 cm per 30.5 m for every 55.6 °C (1 in per 100 ft for every 100 °F) reduction in temperature.

Upon contact with cold nitrous oxide, materials such as rubber or plastics can become brittle and are likely to break without warning.

4.1.1.2 Trapped liquid

Liquid nitrous oxide that is forced to occupy a fixed volume (such as between two closed valves or positive shutoff points) increases in pressure as it warms and expands. As long as there is a vapour space within the volume where the liquid is trapped, the pressure increases approximately 62 kPa per °C (5 psi per °F). When the volume becomes liquid full, the hydrostatic pressure increases at a rate of 10 550 kPa per °C (850 psi per °F). As the temperature continues to increase, the pressure of the trapped liquid can exceed what the piping and components can withstand. This can cause the rupture of the piping or components with possible injury or property damage. For this reason, a pressure relief device (PRD) shall be installed between positive shutoff devices.

4.1.1.3 Personnel overexposure

If sufficient amounts of nitrous oxide are released into the work environment via leaks or venting, personnel exposure levels can exceed occupational exposure limits (OELs) and present a potential risk to health. In addition, gaseous nitrous oxide under atmospheric conditions is 1.5 times heavier than air and therefore, can be found in greater concentrations at lower levels, potentially displacing oxygen in confined spaces and causing an asphyxiation hazard. Nitrous oxide exposure levels should be controlled so that the health and safety risks to personnel are minimised to acceptable levels, i.e., less than the relevant OELs. Nitrous oxide in the gaseous state is colourless and has a sweet odour. Ventilation systems, if required, should be designed to exhaust from the lowest level and allow make-up air to enter at a higher point.

Liquid nitrous oxide forms a mixture of extremely cold liquid and gas when discharged to atmospheric pressure. Nitrous oxide liquid or cold vapour that comes into contact with the skin or mouth can cause freezing or severe frostbite. If frostbite occurs, seek medical attention. Do not rub the area. Immerse in warm water (38 °C to 41 °C [100 °F to 105 °F]).

Liquefied nitrous oxide, UN 1070, is handled in cylinders at a pressure of 5070 kPa at 21 °C (735 psi at 70 °F). Nitrous oxide refrigerated liquid, UN 2201, is stored in insulated tanks at pressures ranging in U.S and Canada from 260 to 315 psi at temperatures of 0 °F to 10 °F and in Europe 20 bar to 25 bar at temperatures of –20 °C to –13 °C.

4.2 Chemical properties and hazards

4.2.1 Oxidizing ability

Under the action of heat, nitrous oxide decomposes into its elements irreversibly and exothermally to produce a mixture that is richer in oxygen than air. See 4.3.2.

$$N_2O \rightarrow N_2 + \frac{1}{2} O_2 + 82 \text{ kJ/mol}$$

As by-products of nitrous oxide decomposition, toxic nitrogen oxides can be formed.

After decomposition, nitrous oxide becomes an oxidizing gas with an oxipotential higher than that of air. Consequently, nitrous oxide is classified in standards and regulations as an oxidizing gas, see Table 4.

Table 4—Nitrous oxide

Reference	**UN number/Shipping name**
United Nations Recommendations on the Transport of Dangerous Goods - Model Regulations [2]	UN No.1070/Nitrous oxide UN No.2201/Nitrous oxide, refrigerated liquid
ISO 10156 *Gas cylinders - Gases and gas mixtures – Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets* [5]	Oxipotential 0.6
NOTE Due to the oxipotential of nitrous oxide, a fire hazard can be created if the gas comes in contact with flammable gases or combustible substances in presence of an ignition source.	

4.2.1.1 Metals

No burning of metals in contact with nitrous oxide has been reported. In theory, the only condition in which metals could burn is after nitrous oxide decomposition.

4.2.1.2 Non-metals

Ignition of non-metals such as plastics, elastomers, and clothing materials in contact with nitrous oxide is possible by the influence of heat (for example, generated by adiabatic compression) or flame.

4.2.1.3 Oil and grease

Oil and grease are unacceptable contaminants in a nitrous oxide installation and can create a severe fire hazard. Such fires can be ignited due to adiabatic compression or high temperature, see 4.3.3.

4.2.1.4 Flammable gases

Flammable gases form explosive mixtures with nitrous oxide, see Table 5. The explosion limits are influenced by the specific chemical properties of nitrous oxide:

- The lower explosion limit of flammable gases is much lower with nitrous oxide than with air or oxygen, since the heat release by decomposition of nitrous oxide supports the combustion of combustible-lean mixtures; and

- The upper explosion limit of flammable gases is much higher with nitrous oxide than with air, since the higher oxipotential of nitrous oxide supports the combustion of combustible-rich mixtures.

Table 5—Explosion limits for some typical flammable gases with nitrous oxide at atmospheric conditions

	Lower explosive limit, mole %			Upper explosive limit, mole %		
	in air 1)	in oxygen 2)	in nitrous oxide 1)	in air 1)	in oxygen2)	in nitrous oxide
Methane	4.4	5.15	1.5	16.5	60.5	49.5
Propane	1.7	2.3	0.7	10.9	52.0	27
Hydrogen	4.1	4.0	2.9	77	94.0	82.5
Ammonia	15.4	15	4.4	33.6	79	65

NOTE—Other literature sources can provide slightly different values, but the general conclusion is that nitrous oxide is more oxidizing than air. For safety precautions with respect to flammable gases, see 5.11.

1) Directive 96/61/EC, *Integrated Pollution Prevention and Control Directive* [6].

2) Directive 2003/87/EC, *Establishing a scheme for greenhouse gas emission allowance trading within the Community* and amending Council Directive 96/61/EC [7].

4.2.2 Stability

Under normal operating conditions, nitrous oxide is a stable compound in both the liquid and gaseous states. Nitrous oxide is classified as a non-flammable gas, with oxidizer as a secondary classification.

It is important for those handling nitrous oxide to understand and avoid sources of decomposition and to understand at what conditions the decomposition front will or will not propagate.

Incidents and experiments have shown that nitrous oxide, as a result of its positive formation energy, can decompose exothermally. This decomposition reaction can be self-sustaining and violent. The theoretical pressure ratio at decomposition, final pressure/initial pressure, can reach 10 to 1 [8].

If improperly handled, nitrous oxide can decompose irreversibly, and potentially explosively, into nitrogen and oxygen:

$$2N_2O \rightarrow 2N_2 + O_2 + \text{Heat}$$

While nitrogen and oxygen are the primary products from nitrous oxide decomposition, the higher nitrogen oxides (NO/NO_2) are also produced.

Decomposition of nitrous oxide is a homogeneous, first order reaction. Nitrous oxide releases 800 Btu/lb (1860.8 kJ/kg) upon decomposition. Nitrous oxide decomposition progresses as a purely thermal process, whereas a propane-air flame front proceeds by a combination of thermal and chain carrier processes. The propagation speed of nitrous oxide decomposition reaction is 30 times slower than the flame propagation speed for propane-air and the reaction is relatively easy to quench [8].

Liquid nitrous oxide is relatively insensitive to high energy sparks or external shocks. Decomposition of the liquid cannot be initiated by an exploding wire in the laboratory. Limited decomposition has been induced in the liquid by blasting caps. Laboratory results indicate that nitrous oxide can be safely handled in the liquid state, but decomposition hazards exist in the gaseous state at elevated pressure and/or temperature. The reaction can propagate through vapour with liquid present [8].

4.2.3 Decomposition sources

All of the following have been known to initiate nitrous oxide vapour decomposition:

- field decomposition sources:
    - static discharge
    - spark (due to metal to metal contact)
    - adiabatic heat of compression
    - secondary exothermic chemical reaction (due to contamination)
    - welding/brazing
    - heat generated by a dry running pump
    - electric immersion heater
    - internal impact
    - external source of heat; and
- laboratory decomposition sources:
    - electric spark
    - exploding wire
    - glowing wire
    - blasting cap
    - heat of compression.

4.2.3.1 Temperature and pressure

Nitrous oxide decomposition will not propagate at relatively low temperatures and pressures, see Figure 1. Three outcomes are possible after a decomposition ignition source has been applied to a pipe or vessel containing nitrous oxide vapour. In order of progressively higher temperature and pressure, they are:

- nothing happens;
- decomposition is initiated, but the reaction is quenched (below the propagation threshold); and
- decomposition is initiated and the decomposition front propagates through the pipe or vessel (above the propagation threshold).

At extreme conditions, for example 301 °C at 354.6 kPa (575 °F at 51.4 psi), nitrous oxide vapour is capable of auto-ignition without an external decomposition source [8].

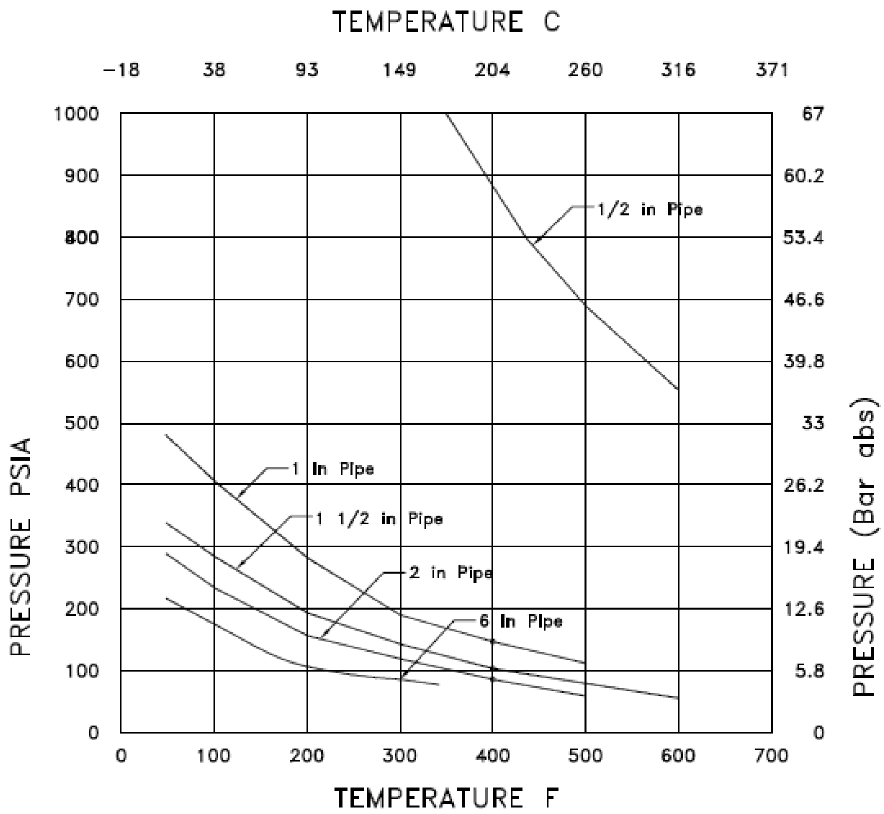


Figure 1—Propagation threshold for nitrous oxide [9]

4.2.3.2 Vessel and pipe geometry

In order for a nitrous oxide decomposition to propagate, the heat generated by the reaction has to be sufficient to heat the next element of unreacted gas to the decomposition temperature. Heat lost to pipe walls reduces the potential for propagating the reaction. Smaller diameter lines have a higher internal surface area to volume. Therefore, in smaller diameter pipes, more heat per unit volume is lost to the pipe walls and higher temperatures and pressures are required for a decomposition front to propagate, see Figure 1.

4.2.3.3 Propagation threshold

The potential for an explosive decomposition to take place is more closely coupled to the quenching characteristics (temperature, pressure, container geometry) of the nitrous oxide system than with the initial decomposition energy [9].

The propagation threshold shown in Figure 1 should be considered as an approximation, but can give the user some indication, if they are handling nitrous oxide greater than or less than the propagation threshold. When handling nitrous oxide vapour under conditions at which the reaction can propagate, care shall be taken to avoid any possibility of a decomposition source.

It is desirable to operate below the propagation threshold by controlling pressure, temperature, or line size.

4.2.3.4 Impurities

Inert gases—Dilution of nitrous oxide vapour with a non-flammable gas such as helium or nitrogen raises the propagation threshold. In one study, the propagation threshold of the pure vapour at 300 psi (2070 kPa) was approximately 480 °F (250 °C). Addition of 20 vol% nitrogen raised the 300 psi (2070 kPa) threshold to 870 °F (465 °C) in the same reactor with the same ignition source. It was not possible to obtain ignition with the addition of 46 vol% nitrogen [10].

Combustible materials—Any combustible material such as hydrocarbon lubricants or flammable mixtures can promote violent decomposition and lower the propagation threshold. A flammable mixture can lower the propagation threshold even if present below the lower explosion limit. All equipment that can be in contact with nitrous oxide shall be cleaned for oxygen service and lubricants shall be oxygen compatible.

4.2.3.5 Large pressure vessels

Most nitrous oxide decomposition incidents have occurred in large pressure vessels such as storage tanks or cargo tanks. As the vapour volume and temperature increase, the risk of disassociation increases. Decomposition can be initiated by a variety of ignition sources, see 4.3.3. The decomposition can also be initiated by external heat (such as welding or brazing) on the vessel or vessel piping, or heat generated by a dry running pump. If initiated in the piping, the reaction front can travel through the piping and into the vessel, if operating above the propagation threshold. Once the reaction front is inside the vessel there is effectively no heat sink to quench the reaction. Since 1.5 moles of gas are created for each mole of decomposed nitrous oxide, the decomposing nitrous oxide compresses and heats the unreacted nitrous oxide as the reaction front moves into the vessel. Eventually, the unreacted nitrous oxide reaches a high enough temperature and pressure to auto-initiate, resulting in an explosion.

Safety practices include:

- Do not weld, braze, or strike an arc on any pipe, cylinder, or vessel that contains nitrous oxide;
- Ball valves and other quick opening valves should be opened slowly. High temperature caused by adiabatic compression could cause nitrous oxide decomposition;
- Nitrous oxide transfer pumps shall be provided with an interlock to prevent dry running, see 7.4.3;
- Piping should operate below the propagation threshold, when possible (see Figure 1). Use the smallest practical line size;

  NOTE Experience has shown that most large diameter vessels operating greater than the propagation threshold have been used safely, because safeguards noted in this publication have been taken (for example, avoiding decomposition initiators).

- Clean all surfaces in direct contact with nitrous oxide as for oxygen, see 5.5;
- Oxygen compatible lubricants shall be used when potentially in contact with nitrous oxide; and
- Direct contact electric immersion heaters shall not be used. This requirement also applies to existing facilities and equipment.

4.3 Occupational exposure

The health effects of nitrous oxide are discussed only with regard to personnel who are involved in transport, filling, and handling of nitrous oxide. The effect of nitrous oxide as a medicinal product is not considered.

4.3.1 Short-term exposure

Nitrous oxide in the gaseous state is colourless and has a sweet odour. Elevated concentrations of this gas in the air can be reached quickly on loss of containment, for example, via leaks and venting. The short-term health effect is primarily the narcotic effect, which includes dizziness, nausea, headache, and loss of coordination. In addition, gaseous nitrous oxide under atmospheric conditions is 1.5 times heavier than air and can be found in greater concentrations at low levels; and therefore, if allowed to displace oxygen in a confined space, can also be an asphyxiation hazard.

Nitrous oxide liquid or cold vapour coming in contact with the skin or mouth can cause freezing or frostbite. If frostbite has occurred, obtain medical attention. Do not rub the area; immerse in warm water (38 °C to 41 °C [100 °F to 105 °F]).

4.3.2 Long-term exposure

Nitrous oxide has been associated with several side effects from long-term exposure. The most strongly substantiated effect is neuropathy. Epidemiological studies also suggest fetotoxic effects and higher incidents of spontaneous abortion in exposed personnel. Although no cause and effect relationship has been firmly established, exposure to the gas should be minimized. National regulations vary the 8-hour time-weighted average (TWA) exposure ranges from 25 ppm to 100 ppm. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends limiting exposure to 50 ppm on an 8-hour TWA basis [11].

4.3.3 Control of exposure to nitrous oxide gas in the workplace

Personnel exposures (for example, filling operators) to nitrous oxide gas should be controlled to acceptable levels (i.e., less than the relevant OELs). Sources of nitrous oxide can include:

- uncontained filling equipment allowing some nitrous to be expelled before/after filling;
- leaking equipment, for example, filling equipment;
- empty cylinders venting to the open air instead of to a blow-down manifold;
- valves not closed sufficiently on empty and full cylinders to ensure no leakage of product; and
- poorly positioned vents leading to re-entrainment of gas into the building.

Control measures should be in place to prevent nitrous oxide leaking or being vented into the workplace. Examples include:

- venting cylinders to a dedicated manifold rig (including purging and vacuum capabilities) that is contained and vented away from the work area;
- ensuring the filling system is designed so that nitrous oxide is not released into the work environment via venting or leaking;
- locating vents outside buildings and above roof level;
- preventative maintenance programme to prevent leaks; and
- written operating procedures, for example, ensuring empty cylinder valves are closed prior to transporting them into the filling area.

If nitrous oxide is stored or filled in insufficiently ventilated rooms, a gas monitoring system should be installed in order to monitor the concentration of nitrous oxide in the room.

4.4 Environmental issues

The emission of nitrous oxide from commercial production is estimated to be approximately 6% of total emissions [12].

In some parts of the world, the release of nitrous oxide to the atmosphere is restricted by regulation.

In Europe, European Union regulations shall be applied and best available techniques need to be used to prevent and minimise nitrous oxide emissions [6, 7]. The Seveso III Directive applies to nitrous oxide, if the quantity present at one time on the site exceeds the following quantities [13]:

- Greater than 50 tonnes (55 tons)—A notification on the quantity of substance and a major accident prevention policy is required; and
- Greater than 200 tonnes (220 tons)—An official safety report is required.

In the United States, the *Emergency Planning and Community Right to Know Act* [EPCRA] (or *Superfund Amendments and Reauthorization Act* [SARA] Title III) Section 311 and 312 regulations apply to nitrous oxide, if the quantity that is present at one time on the site exceeds 10 000 lb [14].

4.5 Security

Nitrous oxide has a multitude of beneficial applications such as an anaesthetic or as a food propellant that ultimately improves the quality of people's lives. When misused, abused, or handled improperly it can harm people, and potentially cause death.

Security measures should be implemented to restrict access to nitrous oxide to authorized personnel only. For more details, see EIGA Doc 922, *Site Security* and CGA P-50, *Site Security Standard* [15, 16]. Security is an issue primarily because nitrous oxide is frequently subject to inhalation abuse. This abuse can result in asphyxiation or long-term exposure health effects, as described in 4.4.2, thereby requiring stricter methods to control access and potential abuse.

For additional security guidance concerning transportation of nitrous oxide and qualifying customers purchasing nitrous oxide, see EIGA Doc 913, *Transport Security Guidance for EIGA Members*, EIGA Doc 920, *Guidance for Qualifying Customers Purchasing Compressed Gases,* CGA P-51, *Transportation Security Standard for the Compressed Gas Industry*, and CGA P-52, *Security Standard for Qualifying Customers Purchasing Compressed Gases* [17, 18, 19, 20].

A policy for the sale of nitrous oxide shall be in place. It shall be ensured by a thorough review before the purchase is approved and the delivery is made that the customer has a valid reason to purchase nitrous oxide and that the tracking records for nitrous oxide shipments shall be maintained.

5. Equipment and procedures

5.1 Principles

The equipment used to handle nitrous oxide shall be designed, constructed, and tested in accordance with the regulatory requirements in the country in which the equipment is operated. The equipment shall be designed to withstand the maximum pressures and temperatures at which it is to be operated and also to minimise the release of nitrous oxide.

Because of the properties and hazards of nitrous oxide, consideration shall be given to avoid combustible materials and any uncontrolled heat input.

General rules described apply to nitrous oxide systems where the pressure is less than 71.5 bar at 36.45 °C (1051 psi at 97.5 °F). For higher pressures (i.e., in the supercritical state of nitrous oxide), rules defined for pure oxygen concerning material compatibility and equipment selection should be considered for nitrous oxide as well. See EIGA Doc 159, *Reciprocating Cryogenic Pumps and Pump Installation*, when applicable [21]. The oxygen rules are also applicable to nitrous oxide and oxygen mixtures irrespective of the partial pressure or percentage of nitrous oxide.

5.2 Compatibility of materials with nitrous oxide

<u>Nitrous oxide is classified as an oxidizer because it forms oxygen when it decomposes, hence the rules for selecting materials in nitrous oxide are often based on the rules for oxygen compatibility.</u> Due to possibility of reaction of materials with nitrous oxide and considering its oxidizing properties, metals and non-metals shall be selected as follows.

5.2.1 Metals

There is no restriction regarding the use of common commercial metallic materials for nitrous oxide installations, see 4.3.1.1. Primarily carbon steel, manganese steel, chrome molybdenum steel, stainless steel, brass, copper, copper alloys and aluminium alloys are considered to be suitable for use with nitrous oxide [3, 22]. <u>Aluminium and its alloys shall not be used in wetted parts of nitrous oxide pumps.</u>

5.2.2 Non-Metals

For examples of non-metallic materials exhibiting the best compatibility with gases having a high oxipotential, see ISO 11114-2 *Gas cylinders – Compatibility of cylinder and valve materials* – Part 2: *Non-metallic materials* [23]:

- Plastic products such as polytetrafluoroethylene (PTFE), polychlorotrifluoroethylene (PCTFE), fluorinated ethylene propylene (FEP), polyether ether ketone (PEEK™), and ethylene propylene diene monomer (EPDM) are acceptable. Others such as polyvinylchloride (PVC), polyvinylidene fluoride, polyamide (Nylon 66®), Vespel® SP21, and polypropylene may be used taking into consideration the external fire risk;

- Certain grades of elastomers such as Viton® or Neoprene® are known to swell in pressurised nitrous oxide and non-swelling grades are preferred when swelling can be an issue;

- Non-metallic materials to be used in high pressure (pressure greater than 30 bar (435 psi)) nitrous oxide/oxygen mixture applications shall conform to specific requirements considering toxicity risks, see EIGA Doc 73, *Design Considerations to Mitigate the Potential Risks of Toxicity When Using Non-Metallic Materials in High Pressure Oxygen Breathing Systems* [24]; and

- Lubricants in contact with nitrous oxide shall be compatible.

5.3 Valves

Materials for high pressure nitrous oxide valves such as cylinder valves shall be selected according to ISO 11114-1, Gas cylinders – *Compatibility of cylinder and valve materials with gas content – Part 1: Metallic materials* and ISO 11114-2, and CGA V-9, *Compressed Gas Association Standard for Compressed Gas Cylinder Valves* [22, 23, 25]. Commonly used metals are brass, copper alloys, and carbon steel. Acceptable non-metallic materials are the plastics PTFE, PCTFE, polyamides, and the elastomer silicon rubber.

Valves for refrigerated liquefied nitrous oxide shall meet the requirements regarding design, testing, and marking for the intended service. See ISO 21011, *Cryogenic vessels – Valves for cryogenic service* [26]. Metallic and non-metallic materials for such valves shall have passed a test for oxygen compatibility such as ISO 21010, *Cryogenic vessels – Gas/materials compatibility* [27]. Ball valves used for liquefied nitrous oxide are recommended to be bored or otherwise designed for pressure relief towards the tank to prevent trapping liquid inside the ball.

5.4 Filters

Filters or strainers, used to trap particles, shall be designed considering the potential oxidizing properties of nitrous oxide (see 5.2). Mesh filters or strainers made from high nickel alloys such as Monel®, Inconel®, nickel 200 alloys, or high copper alloys such as brass are preferred due to increased resistance to oxidizer fires. Stainless steel wire mesh filters have been successfully used in nitrous oxide service without report of incidents of combustion. No glue or similar combustible material shall come into contact with nitrous oxide at pressure greater than 10 bar (145 psi).

Filters or strainers shall not be modified to make a flame arrestor by putting steel wool or similar packing into them. Steel wool is combustible in air and it could contribute towards propagating the decomposition of nitrous oxide rather than quenching it. This requirement also applies to existing facilities and equipment.

Liquid nitrous oxide should be filtered as fine as possible. Hole size of the filter is a compromise between allowable pressure drop, space available, and acceptable thermal mass of the filter body, see EIGA Doc 159 [21].

Gaseous nitrous oxide should be filtered using mesh sizes between 30 and 100 corresponding approximately to a 500 micron to 150 micron particle size capture, see EIGA Doc. 13 *Oxygen pipeline and pipeline systems* [28].

5.5 Cleaning of installation

Any equipment and installation designed for storage and transfer of nitrous oxide service shall be clean for oxygen service according to EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* or ISO 23208, *Cryogenic vessels – Cleanliness for cryogenic service* [29, 30]. With the exception that the maximum quantities of foreign matter (oil, grease, organic materials) in the installation shall not exceed 500 mg/m^2 (50 mg/ft^2). Visible particles, fibres, or drops of water shall not be accepted.

NOTE Nitrous oxide is approximately 44% as effective in promoting ignition as pure oxygen. For this reason, the maximum quantity level of 500 mg/m^2 (50 mg/ft^2) is appropriate.

Where it is necessary to change the product service of equipment from any gas to nitrous oxide, the same rules apply for cleaning. Pressure receptacles that are to be changed to nitrous oxide service shall be cleaned using an appropriate procedure. For cylinders, see ISO 11621, *Gas cylinders—Procedures for change of gas service* or CGA C-10, *Guideline to Prepare Cylinders and Tubes for Gas Service and Changes in Gas Service* [31, 32].

The surfaces that come into contact with nitrous oxide shall be free of all combustible particles and oil and grease that could have been introduced into the system during its construction, fabrication, or maintenance. The equipment shall be clean, as for oxygen service, and if cleaning is needed, detergents or suitable cleaning agents that are free from non-metallic and metallic particles should be used.

5.6 Prevention of contamination

Hoses and filling connections or other pieces of equipment that are not continually connected shall be protected against the ingress of dirt and moisture by caps and/or nuts, when not in use.

5.7 Avoiding high temperatures

High temperatures shall be avoided to reduce the likelihood of an explosive decomposition of nitrous oxide. Figure 1 gives the temperature at which decomposition can propagate depending on pipe diameter and pressure. These correlations are based on limited experimental data and consequently, safety margins shall be considered [9].

Electric heating devices in direct contact with nitrous oxide are prohibited. This requirement also applies to existing facilities/equipment. Only indirect electric heaters with temperature safety controls to prevent exceeding 150 °C (300 °F) are allowed. Water bath heaters, low pressure steam, or other temperature self-limiting devices are recommended.

- All pumps, compressors, or other equipment with rotating or sliding components shall be protected by automatic controls against loss of prime and excessive operating temperatures. This requirement also applies to existing facilities and equipment. Pumps shall not be allowed to operate with no flow or loss of prime. A number of serious incidents have been attributed to overheated equipment. See 7.4.3;

- Liquid transfer pumps should be installed with a flooded suction line and a recycle line return connection to the bottom of the tank to help quench a decomposition reaction during start-up;

- Process hazard analysis (PHA) should focus on prevention of initiation of a decomposition reaction as well as minimizing the possibility of propagation (see Figure 1);

- Historically, strainers have been included in some pump systems with the aim of quenching potential propagation but should not be considered a sufficient safeguard;

  WARNING: *Hot work shall not be performed on any equipment containing nitrous oxide. All equipment shall be purged with an inert gas or air prior to hot work. Be aware that thermal conduction from hot work areas can migrate to piping containing nitrous oxide and lead to an explosion or fire.*

- Medical installations could require purging with medically certified gases per some local regulations during any hot work to prevent the formation of oxides;

- Hot work should not be performed within 1 m (3 ft) of a section of piping that still contains nitrous oxide. Hot work close to a nitrous oxide installation can also require removal of nitrous oxide and purging, depending on the risks and type of work. Such work shall require a work permit issued in accordance with all regulatory and supplier requirements, see EIGA Doc 40 *Work Permit Systems* [33];

- Heat from an open flame or a hot air gun shall not be applied to any part of a nitrous oxide installation for de-icing, releasing threaded couplings, or for increasing pressure in cylinders. However, hot air guns are acceptable when systems are at atmospheric pressure. Use of water as a warming agent is acceptable;

- Thermal mass flowmeters shall not be used due to the internal heater element, unless a risk assessment is carried out to ensure that there is no risk of thermal decomposition. One application is the use of mass flowmeters to measure any emissions to atmosphere through vents;

- Nitrous oxide installations shall be grounded in accordance with local regulatory requirements. See Directive 2014/34/EU, *Equipment and protective systems for use in potentially explosive atmospheres (ATEX)* in Europe, NFPA 70®, *National Electrical Code®* in the United States, or CSA C22.1, *Canadian Electrical Code* in Canada before use in order to dissipate any electrostatic charges [34, 35, 36]; and

- Strainers or filters shall be located in order to avoid migration of particles within specific devices (for example, compressor, pump).

Ball valves and other quick opening valves should be opened slowly. The high temperature caused by adiabatic compression can provide an ignition source that could lead to the rapid decomposition of nitrous oxide (See 4.3.3.5).

5.8 Restriction of flow velocity

Nitrous oxide flow can cause localized heating of a material by particle impact or flow friction, particularly in areas with narrow passages. This heat can initiate a local decomposition/combustion if the decomposition temperature of the material in contact with nitrous oxide is reached. Therefore, the nitrous oxide velocity should be limited to avoid this temperature being achieved.

When designing or modifying an installation, a conservative guide would be to use the velocity limits that are defined for oxygen, see EIGA Doc 13 [28].

5.9 Operating procedures

As with any operation associated with a hazardous substance, written operating procedures shall be prepared. Personnel shall be trained in these procedures.

Management shall ensure personnel understand that the equipment has to be operated within its design parameters, so as not to cause a hazard to personnel or damage to the equipment or environment.

Included in these procedures shall be a statement to indicate that no part of the installation shall be heated higher than the normal operating temperature, see Figure 1.

5.10 Maintenance procedures

Nitrous oxide equipment shall be maintained by qualified and trained personnel in a routine, controlled, and safe manner following written procedures.

Modifications to a nitrous oxide installation or non-routine maintenance work shall not be made without a risk assessment, which may result in a management of change and requirement for a work permit. See EIGA Doc 40 and EIGA Doc 51, *Management of Change* [33, 37].

Consideration shall be given to ensuring that the cleanliness of the system is maintained and that spare parts and lubricants that come in contact with nitrous oxide are compatible with nitrous oxide.

Pressure equipment shall be depressurised prior to any maintenance or repair. If welding or other hot work is to be performed, the system shall be purged with air or inert gas. For information on hot work, see 5.7.

5.11 Isolation from flammable gases

To ensure that there is no hazard of inadvertent mixing of nitrous oxide with flammable gases or liquids, nitrous oxide equipment and pressure receptacles shall be dedicated to nitrous oxide service. Change of service of other equipment shall require a procedure using ISO 11621 or CGA C-10 [31, 32]. Cylinders and tubes may be converted to another gas service in accordance with ISO 11621 or CGA C-10 [31].

Where nitrous oxide has to be mixed with other gases, precautions shall be taken to ensure that no flammable gas is unintentionally mixed with nitrous oxide, see EIGA Doc 39, *The Safe Preparation of Gas Mixtures* [38]. Mixtures of nitrous oxide with flammable gases shall only be produced in accordance with EIGA Doc 139, *Safe Preparation of Compressed Oxidant-Fuel Gas Mixtures in Cylinders* [39].

Mixing of nitrous oxide with self-igniting gases such as silane shall be prevented under all circumstances, since immediate ignition and explosion can occur. Some processes that use nitrous oxide and self-igniting gases such as silane in separate steps shall be protected with effective backflow preventive devices to prevent backflow of gas.

5.12 Use of carbon dioxide equipment

Carbon dioxide equipment, which has similar temperature and pressure requirements to nitrous oxide, shall not be used for nitrous oxide service unless a conversion procedure has been followed for the change of service. For gas cylinders, see ISO 11621 and CGA C-10 [31, 32]. The procedure shall meet the relevant requirements of this publication or any other applicable standard or regulation. Care shall be taken with regard to design, material, insulation, cleanliness, lubricants, seals, and avoiding high temperatures.

Medical installations shall follow national regulations regarding cleaning and certifying, if applicable.

WARNING: *Unlike carbon dioxide, nitrous oxide shall not be used as a pneumatic energy source to actuate pneumatic cylinders, valve actuators, or as an inert gas.*

6. Stationary tanks

Stationary tanks are used in nitrous oxide production plants, filling plants, and customer installations. This section refers to all these types of tanks.

6.1 Design

There are two different tank types as follows:

- insulated tanks; and
- non-insulated high-pressure tanks.

6.1.1 Insulated tanks

Insulated tanks are used for the storage of refrigerated liquid nitrous oxide at temperatures less than –20 °C (–4 °F) and corresponding vapour pressure in the range of 18 bar to 25 bar (260 psi to 362 psi).

The typical maximum allowable working pressure (MAWP) for nitrous oxide tanks ranges from 16 bar to 25 bar (232 psi to 362 psi). The normal operating conditions are 17.7 bar to 21.4 bar (257 psi to 310 psi) at corresponding temperatures of –16 °C to –12 °C (0 °F to –10 °F). The minimum design metal temperature (MDMT) shall be less or equal to the minimum normal operating temperature. Newly constructed tanks should have an MDMT of –40 °C (–40 °F) or colder to better handle the low temperature upset conditions caused by loss of tank pressure.

There are two types of insulated tanks:

- Vacuum insulated tanks with the inner tank typically made from stainless steel or fine grain carbon steel and the outer tank from carbon steel. Vacuum insulated tanks have the lowest external heat input to the inner tank and are therefore less susceptible to external heating caused by fire or ambient heat that could lead to a decomposition of the nitrous oxide; and

- Non-vacuum insulated tanks with the inner tank typically made of low alloy carbon steel and the outer cladding made of steel or aluminium.

Insulation material:

- Insulation system shall be non-combustible or fire resistant. For example, the material shall not continue to burn when the external flame is extinguished;

- Insulation system made of polyurethane with cladding made of steel or aluminium is considered to be fire resistant; and

- If the insulation system of an existing tank has to be replaced, it should be rebuilt using a fire-resistant insulation system (for example, polyurethane with cladding) or non-combustible material such as glass wool, foam glass, or mineral wool. A suitable vapour barrier is required to prevent the insulation from becoming saturated with condensed moisture.

6.1.2 Non-insulated high-pressure tanks

Non-insulated high-pressure tanks are typically made of carbon steel for the storage of liquefied nitrous oxide at ambient temperature and corresponding vapour pressure in the range of 45 bar to 60 bar (640 psi to 900 psi) corresponding to a temperature range of 13 °C to 27 °C (56 °F to 82 °F). The high operating pressure of this tank type requires high pressure filling pumps and sometimes the use of two pumps in series. This increases the hazard of heat production and subsequent decomposition. Furthermore, in case of an external fire, the tank content can be heated up rapidly. Because of the increased potential for decomposition in such conditions, the use of non-insulated tanks shall be discouraged unless a risk assessment has been completed and mitigation has been provided.

6.1.3 Tank installation

Safety requirements and recommendations for all stationary tank types include:

- Tanks shall be installed on an engineered foundation that meets all local and national building codes;

- Support and foundation of the tanks should be non-combustible;

- Tanks should be installed outdoors. In the very rare cases where indoor installation is necessary, ventilation and access for filling shall be provided. Nitrous oxide or oxygen deficiency levels in the ambient air shall be monitored. Further information on the hazards in indoor installations is documented in ISO 21009-1 *Cryogenic vessels – Static vacuum insulated vessels – Part 1: Design* *fabrication, inspection and tests* or CGA G-8.1, *Standard for Nitrous Oxide Systems at Consumer Sites* [40, 41];

- Tanks shall be located away from any potential fire situation. Local regulations concerning safety distances shall be observed, see EIGA Doc 224, *Static Vacuum Insulated Cryogenic Vessels Operation and Inspection* [42];

- All parts of nitrous oxide tanks shall be bonded to ensure electrical continuity and grounded. The electrical potentials between the tank and the ground should be equalised during service; and

- Some old nitrous oxide tanks (including old carbon dioxide tanks) were manufactured using coarse grain low alloy steels that have been shown to have poor impact properties at low temperatures. Because of similarities between nitrous oxide and carbon dioxide properties, the recommendations in CGA G-6.12, *Standard for the Suitability of Carbon Steel Containers for Stationary Carbon Dioxide Storage* should be considered [43].

6.2 Refrigeration units

A mechanical refrigeration unit is typically installed on non-vacuum insulated tanks and on some vacuum insulated tanks. The refrigeration unit is used to reduce the tank pressure by condensing vapour which prevents discharging nitrous oxide to the atmosphere. Installations that fill cylinders typically require a refrigeration unit sized to overcome the ambient heat input introduced by the filling process. See EIGA Doc 83, *Recommendations for Safe Filling of CO2 Cylinders and Bundles* for reference to similar carbon dioxide filling procedures [44]. The refrigeration evaporator coil is typically installed in the tank vapour space and shall have as few joints as possible and be all welded or brazed.

WARNING: *Mixing of hydrocarbon refrigerants and oils with nitrous oxide can lead to a violent reaction within the refrigeration system. Therefore, to avoid the risk of refrigeration coil leaks, no mechanical fittings inside the tank on the refrigeration evaporator are allowed.*

It is suggested that when older fluorocarbon refrigeration systems are repaired that they be converted to synthetic lubricants such as polyolester (POE) that have a higher flash point. Refrigeration compressor failure or high pressure throughout the refrigerant circuit can be an indication of a nitrous oxide evaporator coil leak and should be thoroughly investigated.

No hot work (brazing) on the refrigeration system is allowed without first emptying and purging the container of nitrous oxide and purging with an inert gas.

6.3 Vaporizers and heaters

Nitrous oxide is a liquefied gas, which means that withdrawal of vapour or liquid from the tank can cause the remaining liquid to partially boil and auto-refrigerate. Continued product withdrawal can cause the pressure and temperature of the remaining liquid to decrease. The temperature of the tank shall not be allowed to decrease below the MDMT (see 6.1.1). Pressure building or direct to process vaporizers are generally required to provide sufficient external heat to maintain a safe operating pressure.

Vaporizer heat sources such as electric heating elements shall not be installed inside the tank because overheating can cause explosive decomposition of nitrous oxide.

A small ambient air heated pressure build-up coil can be sufficient to maintain the required pressure. In colder climates, an externally heated vaporizer could be required. Liquid is evaporated and the vapour re-introduced at the top of the stationary tank.

An external vaporizer is required in the withdrawal system at customer installations if nitrous oxide is to be used in the gaseous state.

If an external indirect heated vaporizer has to be used, then the heating shall be controlled to limit the temperature to a maximum of 150 °C (300 °F). Direct heating such as warm water, steam, and warm air are safer and therefore recommended. Where electrical heating is used, additional safeguards are required to ensure a maximum temperature limit of 150 °C (300 °F). Direct electric coils shall not be used.

A back-pressure control valve (economizer) may be used to prevent a tank from pressure increase, as sometimes the withdrawal rate is less than the boil-off rate.

6.4 Piping, instrumentation, and valves

The tank shall have a contents pressure gauge and liquid level/weight indicator.

The piping and instrumentation shall enable the following functions:

- Filling of liquid into the bottom of the tank. This allows a potential decomposition starting at the pump to be quenched in the liquid phase;

- Product withdrawal by bottom line or via dip tube or through a vapour line if used to maintain tank pressure;

- Gas return to and from the top to accommodate the two-hose filling procedure with pressure compensation between the stationary tank and transport tank;

  ***WARNING**: If there is any known risk of back contamination for example, by impurities coming from customer tanks, this method may only be used if mitigating measures have been taken.*

- Level indicator, for example, scale, load cell, or differential pressure gauge. The maximum filling weight shall be marked. A dip tube intended to prevent a liquid full condition is an acceptable practice in lieu of marking the maximum filling weight. Typical liquid level indicators operate by measuring the differential pressure between the top and bottom of the container. In low ambient temperature conditions, such gauges can require heat tracing to prevent recondensing of the vapour in the sensing lines. Any heat tracing shall use inherently safe methods to prevent temperatures from exceeding 150 °C (300 °F);

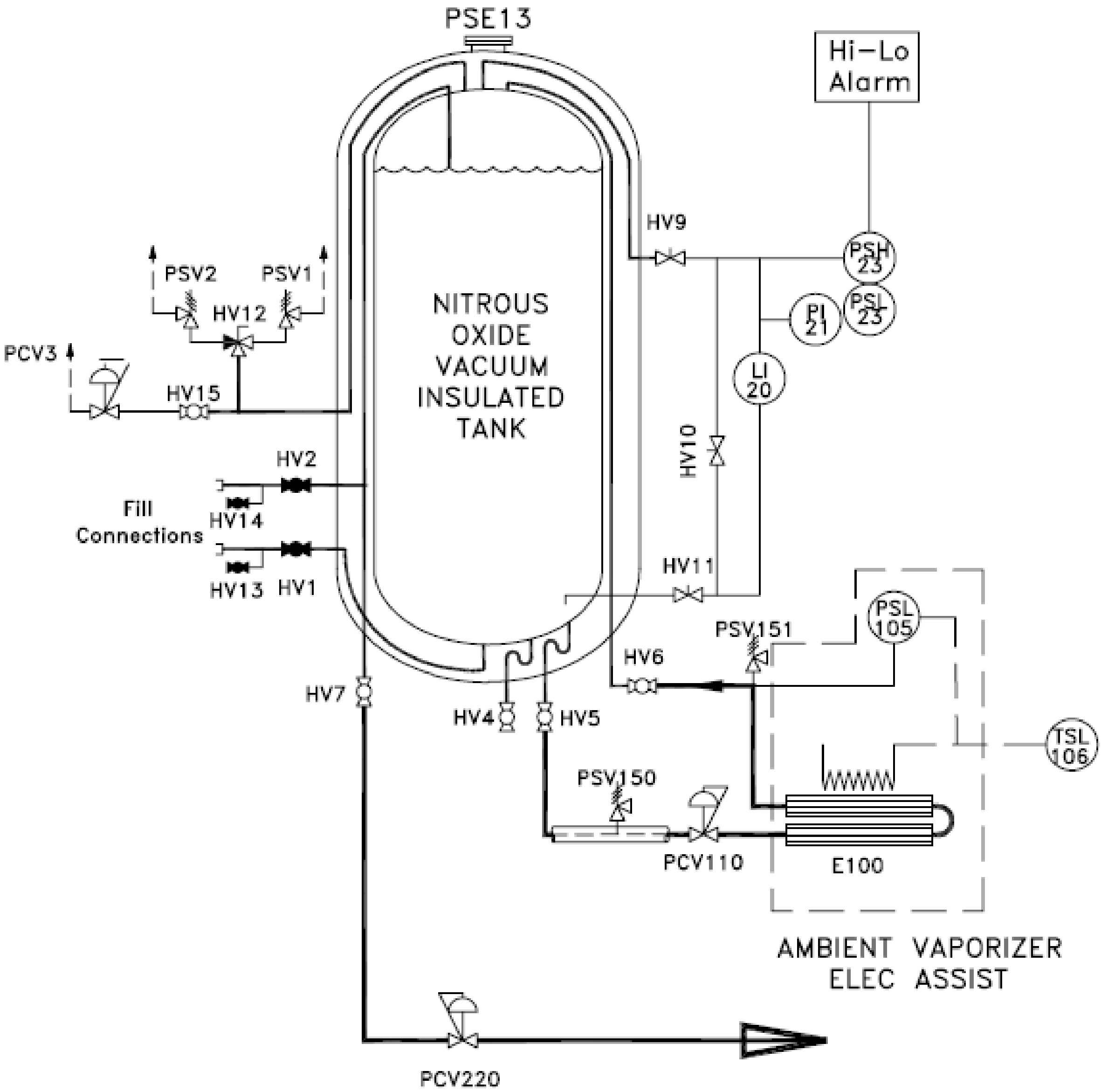
- Pressure gauge to monitor the tank pressure. It can be combined with an alarm function for high and low pressure;

- Maximum liquid level check by gas return line or full trycock depending upon tank design; and

- Precautions against overpressure as a result of overfilling. Procedures and/or equipment shall be installed after a risk assessment has been performed, see EIGA Doc 151, *Prevention of Excessive Pressure During Filling of Cryogenic Vessels* [45].

The diameter of process piping should be kept to a minimum to reduce the decomposition propagation threshold subject to operating constraints (see 4.3.2).

An example of a piping and instrumentation diagram (P&ID) of a stationary nitrous oxide tank is provided in Figure 2. The P&I of nitrous oxide tanks can be different, depending on company standards and user's demands.



Valve legend—Liquid nitrous oxide tank			
PSV1 and PSV2	Valve, safety relief	HV9	Valve, level gauge vapor (LP)
PCV3	Valve, back pressure control	HV10	Valve, level gauge bypass
PSE13	Vacuum space relief device	HV11	Valve, level gauge liquid (HP)
PSH23, PSL23	Switch, hi-low pressure	HV12	Valve, selector relief valve
LI20	Gauge, liquid level	HV13	Valve, blowdown liquid fill
PI21	Gauge, tank pressure	HV14	Valve, blowdown vapor fill
HV1	Valve, liquid fill	HV15	Valve, isolation economizer
HV2	Valve, vapour fill	E100	Vaporizer, pressure build
HV3	Valve, pressure build liquid supply	PCV110	Valve, vaporizer pressure control
HV4	Valve, liquid use	PSL105	Switch, vaporizer low pressure
HV5	Valve, pressure build liquid use	TSL106	Switch, vaporizer low temperature
HV6	Valve, pressure build vapour return	PSV150 and PSV151	Valve, thermal safety relief
HV7	Valve, liquid use	PCV220	Valve, backpressure control, vapour

Figure 2—P&I diagram of a typical nitrous oxide vacuum-insulated stationary tank

6.5 Pressure relief valves

Each stationary nitrous oxide bulk tank shall have two active safety relief devices sized and designed to meet all local and national regulations. Typically, there are two active spring-loaded relief valves or one active spring-loaded relief valve plus a pressure control valve. They shall conform to regulations and standards such as EIGA Doc 24, *Vacuum Insulated Cryogenic Tank Storage Systems Pressure Protection Devices* and ISO 21013-1 *Cryogenic vessels – Pressure relief accessories for cryogenic service. Part 1: Reclosable pressure relief valves* [46, 47].

It is recommended that a three-way selector valve, sized for the tank operating conditions, be provided for the safety relief device(s) to allow servicing and maintenance of the device without requiring the depressurization of the container.

Rupture disks are not usually recommended for use in nitrous oxide tank service because they will not reseat after the tank pressure has decreased, which can cause the remaining liquid to boil violently and auto-refrigerate to –88 °C (–127 °F). This situation could be critical if the inner vessel is made of carbon steel, which would require specific repressurization procedures that have been risk evaluated by a knowledgeable nitrous oxide technician.

6.6 Filling degree or filling ratio

The filling degree or filling ratio shall be verified for each stationary nitrous oxide tank.

Insulated tanks should be filled to a level that prevents them from reaching a liquid full condition before the vapour pressure reaches the PRD setting. When liquid nitrous oxide is stored in a tank and there is no product withdrawal, heat leak causes the temperature and pressure to rise and the liquid to expand. If the tank becomes liquid full, the hydrostatic pressure rise can cause its catastrophic failure.

The safe filling degree depends on the temperature of the liquid being transferred into the tank and on the pressure at which the PRD is set to open. The colder the liquid, the more vapour space is required for liquid expansion. According to some national regulations and practical experiences, the filling degree of insulated tanks shall not exceed 95%.

The maximum filling level can be easily controlled by the gas return line or full trycock depending upon tank design.

Non-insulated high-pressure tanks can be filled to the same maximum filling ratio as applied to cylinders and bundles, see 7.1.

6.7 Filling of stationary low-pressure tanks

When stationary tanks are filled by a pump, for safety reasons the two-hose procedure should be applied in order to minimize pressure. After the distribution supply system has been evaluated and has been determined that there is no possibility of back contamination from the gas phase to the transport tank, filling should be made through the bottom fill line. Tanks should not be filled by pump through the top equalizing line or any other line to the top. If filling is performed by pressure difference only without the use of a pump, the tank may be filled through the top line.

The pressure between the transport tank and the stationary tank should be equalized to ensure a smooth pump operation and to prevent creating any hot spots. Pump discharge pressure or flow shall be monitored to ensure that the pump is operated within the performance conditions. The pressure and the level indicator of the stationary tank shall be monitored to avoid overfilling. The full trycock or vapour return shall be opened at the end of filling to verify that the tank is not overfilled.

6.8 Product return

If the tank needs to be emptied, for example, for maintenance, it may be necessary to return the product to the supplier.

This can only be performed under supervision of qualified personnel, observing specific procedures. Precautions shall be taken to avoid temperatures lower than the design temperature of the tank (see 6.1). Truck pumps should not be used for emptying stationary tanks. If no suitable pump is available, pressure transfer shall be used.

7. Supply equipment

7.1 Cylinders

It is recommended to dedicate a stock of cylinders to nitrous oxide service. Any change of service to or from nitrous oxide shall be made in accordance with ISO 11114-1, ISO 11114-2, and ISO 11621 or CGA C-10 [22, 23, 31, 32].

Suitable materials for nitrous oxide cylinders are carbon steel, chrome molybdenum steel, aluminium alloys, and stainless steel, see ISO 11114-1 [22]. Cylinders made of non-metallic materials, for example, full composite (type 4), shall not be used.

Valve outlet connections shall be in accordance with national standards, where available and applicable, to avoid mix up of connections. The design and testing of valves shall follow the standards and valve materials shall meet the requirements in ISO 11114-1, ISO 11114-,2, CGA S-1.2, *Pressure Relief Device Standards—Part 2—Portable Containers for Compressed Gases,* and CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases* [22, 23, 48, 49].

Dip tubes made of non-metallic materials shall not be used because of the risk of static electricity buildup. Where metallic dip tubes are used, electrical continuity shall be ensured for all parts of the cylinder and its accessories. Ensure there is no risk of separation of the dip tube from the valve occurs during service. For these purposes, it is recommended no later than the first retest to weld or to solder the connection between the dip tube and the cylinder valve. The valve shall be mounted so electrical continuity is ensured.

Cylinders should be filled by weight to ensure accurate fill level. To avoid accidental overpressure in the cylinder by overfilling, some regional regulations require valves to be fitted with a bursting disk; where this is not the case, the use of bursting disk is recommended. The set pressure of the bursting disk is established by local regulations or company specifications (for example, 5/3rds of workingpressure in the United States and Canada but shall not exceed 1-15 times the test pressure of the gas cylinder including all tolerances. Under no circumstances shall disks with fusible metal backing devices be used because they do not protect against cylinder overfilling.

7.2 Bundles

Where bundles are used for transporting and storing nitrous oxide, the individual cylinders in the bundle are usually manifolded together and terminate with one connection point for filling and discharge. Bundles are fitted with a main isolation valve. If cylinders are equipped with isolation valves, each cylinder in the bundle shall be equipped with a bursting disk and shall be filled individually.

U.S. and Canadian regulations require each cylinder to have a relief device.

Where individual cylinder valves are used, see CGA SB-34, *Product Migration in Manifolded Cylinders Due to Temperature Variations* for information on possible product migration [50].

Where non-closable fittings are used on each cylinder in the bundle only one bursting disk may be used to protect the bundle. If cylinders are equipped with individual valves, these valves and the main valve shall be equipped with a bursting disk.

The bundle shall be designed, manufactured, and tested according to any applicable regulatory requirements and where appropriate a design code, for example ISO 10961 *Gas cylinders. Cylinder bundles – Design, manufacture, testing and inspection* [51].

Each individual cylinder shall be in accordance with 7.1. Pipes of metallic materials should be used for the manifold. Connections within the manifold should preferably be welded or soldered.

7.3 Transport tanks

Insulated transport tanks are used for the transport of nitrous oxide refrigerated liquid. They shall fulfil the requirements of local transport regulations. For example, see *European Agreement Concerning the International Carriage of Dangerous Goods by Road* (ADR), or U.S. *Code of Federal Regulations* (49 CFR) and *Transportation of Dangerous Goods Regulations* for the United States and Canada [52, 53, 54].

Requirements to build such transport tanks are specified for vacuum insulated transport tanks, for example, ISO 20421-1, ISO 20421-2, EN 14398-1, EN 14398-2, and EN 14398-3 [55, 56, 57, 58, 59]. Refer to the applicable European, U.S., and Canadian requirements and the *International Maritime Dangerous Goods* (IMDG) Code for international shipments by sea [60].

This section applies also for cryogenic liquid cylinders up to 450 L (118 gal). See EN 1251-2, *Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 litres volume – Design, fabrication, inspection and testing* or ISO 21029-2, *Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 litres volume – Part 2: Operational requirements* [61, 62].

7.3.1 Insulation

Vacuum-insulated transport tanks are acceptable for use.

If non-vacuum-insulated transport tanks are used, the insulation should be fire resistant (see 6.1). Where there are connections that could leak, for example, manhole flange, pipe flanges, screwed pipe, they shall be separated from any non-fire-resistant insulation material. The insulation material shall be completely covered by a protective metal cladding.

7.3.2 Material

Suitable materials are aluminium, fine grain carbon steel, and stainless steel for the tank including the baffles and accessories. Transport tanks manufactured after 1975 shall have a MDMT of –40 °C (–40 °F) or lower and are commonly designed for a maximum working pressure of 24 bar (348 psi).

Material that can come in contact with the transported product should be approved for nitrous oxide. If no data are available on nitrous oxide compatibility, oxygen compatibility rules should be applied, for example, according to ISO 21010 [27].

7.3.3 Piping and instrumentation

Pipes, valves, flanges, couplings, etc. shall be metallic. Seal and gasket materials shall be selected according to 5.2.

The piping and instrumentation shall enable the following functions:

- Filling of liquid into the bottom of the transport tank. This would allow a potential decomposition reaction starting at the pump to be quenched in the liquid phase;
- Product discharge through the bottom line;
- Gas return to and from the top for the two-hose filling procedure with pressure compensation between transport and stationary tank. A spray line in the top shall only be used during the initial cooling of a warm tank with product transfer from differential pressure (without the use of a pump);
- At least one full trycock or vapour return line in order to check the filling level limit;
- Level indicator to monitor the tank contents as an option;

- Pressure gauge to monitor the tank pressure;
- Pressure gauge to monitor the pump discharge pressure or differential pressure; and
- Connections to allow sampling of liquid phase and, as an option, gas phase.

7.3.4 Grounding

All parts of the transport tank shall be bonded to ensure electrical continuity. This can be achieved by either a ground cable or a conductive hose.

7.4 Pumps

For transfer of refrigerated liquid nitrous oxide, the following pump types are currently used:

- gear pumps;
- sliding vane pumps; and
- centrifugal pumps.

Pump design requirements for liquid oxygen pumps should be considered, see EIGA Doc 148, *Installation Guide for Stationary, Electrical-Motor Driven, Centrifugal Liquid Oxygen Pumps* and ISO 24490, *Cryogenic vessels – Pumps for cryogenic service* [63, 64].

In addition, the design of the pump has to take into account ways of avoiding sources of heat or sparks that can lead to an ignition and/or decomposition of nitrous oxide:

- Bearings that are lubricated by nitrous oxide should be avoided. Bearings that are running outside the product containing part of the pump are preferred;
- Consequences of failures and consumption of wearing parts shall be considered. The periods of maintenance shall be taken into consideration;
- Clearances between moving and stationary parts within the pump shall be as large as practical, consistent with hydraulic performance and sealing;
- Fastenings of construction elements shall be secured to prevent them from loosening during service;
- Mechanical seals are recommended; and
- Material combinations of moving and stationary parts shall be selected to ensure that there is a low probability of ignition and spark production.

7.4.1 Installation

The pump shall be installed at the lowest point of the line so that the pressure drop on the suction side is as small as possible in order to meet the required net positive suction head (NPSH):

- Suction line should be as short as possible and its diameter should be equal to or greater than the diameter of the pump's suction inlet. The suction pipe shall be designed according to pump manufacturer's instructions to ensure a sufficient NPSH;
- Suction pipe shall have as few bends as possible;
- Suction line shall be fitted with a filter that shall have as little pressure drop as possible;

- Valves in the suction line should be capable of providing a full flow passage, for example, ball valves;
- An emergency shut off valve either manual or automatic should be installed in the suction line;
- The external forces on the pump should be minimised, for example, by using flexible pipes within the suction and discharge lines; and
- The pump should be separated from the pump motor.

All parts of the pump shall be bonded to ensure electrical continuity.

7.4.2 Lubrication

Pump lubricants that can come in contact with nitrous oxide shall be oxygen compatible, see EIGA Doc 148 or ISO 24490 [63, 64].

7.4.3 Dry running protection

The primary hazard during pump operation is dry running, which leads to heating and damage of the pump. Nitrous oxide can overheat and cause a decomposition reaction that can lead to an explosion. Dry running is most often experienced at start-up of the pump and when loss of prime occurs during operation, for example due to the source tank becoming empty.

Provide an interlock system that allows the pump to start only after it has been cooled down and filled with liquid product, which protects the pump from dry running. Depending on the type of pump and usage, the system may be activated by differential pressure, temperature control, motor current, and/or a suitable mass flow measuring device. Temperature measurement is the preferred method for permissive start since it does not require a bypass (override) to allow the pump to start and establish pressure and current or flow parameters. However, if such interlock override is employed it shall be automated with a time delay and not accessible to operators to defeat (i.e., no manual override).

A trip function shall also be provided to protect against loss of prime during operation. This shall be based on one or more measurements of the types noted previously. The protection system shall be considered critical for safety and evaluated according to recognized standards such as IEC 61511, *Functional safety - Safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and application programming requirements* or ANSI/ISA 84, *Functional Safety: Safety Instrumented Systems for the Process Industry Sector - Part 1: Framework, Definitions, System, Hardware and Software Requirements* to ensure an adequate number of protections, independence of devices, and integrity of trip function through to final element (stopping the pump) is achieved [65, 66]. No operator or maintenance bypass (overrides) shall be provided.

These requirements also apply to existing facilities and equipment.

7.5 Hoses, accessories, and couplings (fill connections)

Hoses are used for the transfer of liquefied nitrous oxide at ambient temperature or refrigerated liquid nitrous oxide at low temperature.

Hoses shall be designed, manufactured, and tested to withstand the temperature and pressure for the intended service, see ISO 21012, *Cryogenic vessels - Hoses* or the American Society of Mechanical Engineers (ASME) B31.3, *Process Piping* [67,68]. Suitable materials of construction for hoses and other accessories (valves, pressure relief valves, flanges, pipes) are carbon steel, stainless steel, and copper alloys. If other materials are used, for example, for seals etc., the oxygen compatibility shall be considered, see ISO 11114-2 (ambient temperature service) or ISO 21010 (low temperature service) [23, 27].

Transfer hoses shall be protected against the ingress of dirt and moisture by caps and/or nuts, when not in use.

Hose couplings shall meet standardized basic requirements such as leak tightness or application by hand tools in a controlled manner, see EN 13371, *Cryogenic vessels – Couplings for cryogenic service* or CGA V-6, *Standard Bulk Refrigerated Liquid Transfer Connections* [69,70]. The couplings should be designed to avoid confusion between different gases. Bolted flange couplings only partly meet the requirements. Both in Europe and United States dedicated couplings have been adopted, see EIGA 909, *EIGA cryogenic gases couplings for tanker filling* or CGA V-6, for tanker filling [71, 70]. The EIGA coupling is not intended to be used for filling customer tanks.

The coupling for the liquid filling line shall be different from the coupling for the gas return line in order to avoid confusion between liquid and gas.

All hoses, accessories, and couplings shall be constructed so that electrical continuity is ensured.

The fill and product discharge connections of small transportable cryogenic containers should be permanently attached to the container by welding, brazing, a mechanical locking device (medical), or wire ties (industrial) as required by regional regulations.

Hoses shall be inspected and maintained at frequencies defined per national requirement as a minimum and the unloader should visually inspect the hose prior to each product transfer. See CGA P-82 *Standard for Maintenance of Transfer Hoses* for hose requalification [72].

8. Product transfer

8.1 Cylinders and bundles

Cylinder and bundle filling stations shall be designed and built to withstand the pressure loads and the external loads during service to allow safe filling.

Nitrous oxide cylinder and bundle filling stations consist of the following main elements:

- Vacuum- or non-vacuum-insulated stationary tank, working pressure approximately 20 bar (290 psi) or non-insulated high-pressure tank working pressure approximately 80 bar (1160 psi);

- Reciprocating pump working pressure up to 100 bar (1450 psi). The pump should be equipped with protection against dry running, for example, by means of a thermocouple to monitor the temperature on the discharge side. Where the lubricant could be in contact with nitrous oxide, only oxygen compatible lubrication shall be used;

- Pump bypass if the pump is running continuously;

- If not equipped with a bypass line, the pump shall be automatically switched off when the cylinders are full;

- Partially or fully insulated pipe from the pump to the filing point;

- Filling scales with the required accuracy for large and small cylinders;

- Cylinder or bundle emptying manifold with vacuum pump; and

- Flexible filling hoses, which should be equipped with safety cable or equivalent system to prevent whipping if broken under pressure.

The following additional requirements shall be met:

- The installation shall be designed and operated in accordance with local regulations for oxidizing and medical gases;

- Written operating procedures, which describe all steps of the filling process (prefill check and reconditioning of the cylinders, tare weight check, control of filling weight) shall be provided. For details of a recommended gravimetric filling procedure, see *ISO 24431 Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene)* [73]

- Filling of non-empty cylinders (top filling) and filling by pressure without scale shall not be permitted; and

- Cylinders shall be filled to the permissible filling ratio. The filling ratio is dependent on the test pressure of the cylinder, see Table 6 or by local regulations. In the United States and Canada, the filling ratio is 70.3% for a 2000 psi rated cylinder, 73.2% for a 2265 psi rated cylinder, and 74.5% for a 2400 psi rated cylinder.

Table 6—Extract from Packing Instruction P200 [2]

Minimum cylinder test pressure, bar	Maximum filling ratio
180	0.68
225	0.74
250	0.75 1)
1) This means, for example, that a cylinder with a 10 L capacity and test pressure of 250 bar (3625 psi) may be filled with 7.5 kg of nitrous oxide.	

All parts of a filling installation shall be bonded and earthed to ensure electrical continuity. The electrical potentials between the cylinder or bundle and the ground should be equalised during filling. If necessary, the cylinder or bundle should be bonded directly to ground.

8.2 Transport tanks

Refrigerated liquid nitrous oxide is normally transferred from a stationary tank at the production plant into the transport tank and then transported to the user.

A ground-mounted pump adjacent to the stationary tank is commonly used to fill the transport tank. The suction pipe shall be designed according to pump manufacturer's instructions ensuring a sufficient NPSH. The on-board pumping system of the transport tank should not be used as the pump suction is not designed for this type of transfer.

An inherently safer design employing an elevated stationary tank to fill the transport tank via gravity using the two-hose filling procedure eliminates the risk from loss of prime when pumping nitrous oxide into an empty trailer (vapour space). This should be considered for new tank installations. In addition, the transport tank filling area:

- Filling connection area should be covered with non-combustible material (such as concrete or natural stones). Wood is not acceptable;

- Transport tanks should be equipotential bonded to the stationary tank during product transfer; and

- Connections, seals, and transfer hoses shall be kept clean by using caps, plugs, etc.

Transport tanks should be filled by the two-hose filling procedure in order to minimize pressure differential and the hazard of decomposition. Filling shall be made through the bottom fill line and the gas phase shall be directed back to the stationary tank. Filling through the top equalizing line or any other line to the top is not recommended in order to avoid heat input into the gas phase by a hot running pump.

During filling, the pump discharge pressure shall be monitored to ensure that the pump operates within the specified performance conditions. The pressure and the level indicator (if any) of the transport tank shall be monitored to avoid overfilling. At completion of filling, the full trycock shall be opened to verify that the filling quantity is correct. If designed for the function, the vapour return may serve as the full trycock.

Further operational requirements for vacuum-insulated transport tanks are addressed in ISO 21029-2 and for non-vacuum-insulated transport tanks in EN 14398 Parts 1 to 3, ADR, and 49 CFR 178.331 [63,58,59,60,53,54].

The principles of safe filling of transport tanks can also be applied for cryogenic receptacles.

8.2.1 Filling degree

The filling degree shall comply with local regulations. In absence of local regulations, the maximum filling degree shall be 95%.

Figure 3 indicates the pressure effect of overfilling a tank caused by the expansion of liquid.

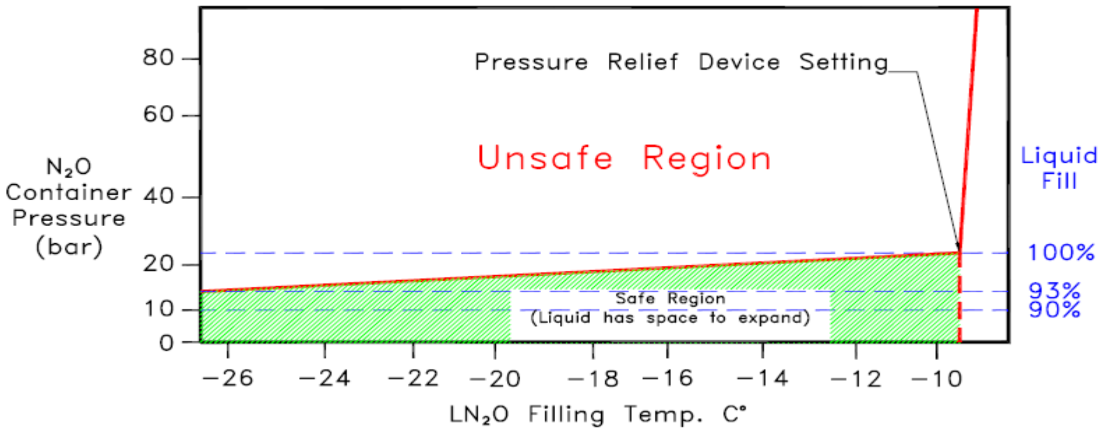


Figure 3—Safe filling volumes for 22 bar nitrous oxide storage tanks

9. Emergency response

9.1 Hazards

For information regarding the hazards associated with nitrous oxide, see Section 4.

9.2 Procedures for large leaks or spills of nitrous oxide

Isolate the leak without putting personnel at risk. If possible, orient leaking containers so the gas escapes rather than the liquid.

In the absence of regulatory or dispersion model guidelines, isolate the area affected by the spill or leak for at least 25 m to 50 m (75 ft to 150 ft) in all directions, keep unauthorized persons away, and stay upwind. A large spill (e.g., unrestricted open pipe flow) may require a greater distance due to the increased volume of the discharge.

Reasonable measures shall be taken to prevent the leaking gas or liquid from reaching low lying areas and try to prevent entry into drains, sewers, basements, or confined spaces.

Ventilate and check confined spaces and rooms before entering. The check shall be conducted by competent personnel who are trained to detect potential atmospheric hazards.

Emergency responders shall avoid water contact with the pressure relief valves to avoid freezing the pressure relief valves closed.

Do not touch or walk through spilled liquid.

Try to prevent contact of cold nitrous oxide (liquid or gas) with materials that are sensitive to cold such as rubber or plastics.

Never use any absorbents, especially sawdust or other absorbent materials on liquid nitrous oxide spills.

9.3 Procedures at fire situations

Plant personnel should be restricted to fight only minor fires, if trained and equipped for such occurrences. Emergency responders should fight large fires. Evacuation of the plant is recommended if there is a fire in the nitrous oxide area.

9.3.1 Fires involving combustible materials with nitrous oxide

Nitrous oxide can strongly support the combustion of materials such as wood, paper, oil, clothing, etc.

In dealing with any fire situation, these materials shall be kept at a safe distance from the fire.

Materials burning in nitrous oxide can produce irritating and toxic gases. Emergency responders should use respiratory protection while extinguishing fires.

Use a suitable extinguishing agent for the type of fire in question such as dry chemical, carbon dioxide, or water spray.

9.3.2 Fire in the area of nitrous oxide tanks

Tanks and pressure receptacles that are exposed to fire or extreme heat can rupture due to increase of temperature and pressure. In addition, nitrous oxide tanks and pressure receptacles can be subject to explosive decomposition, which can occur in spite of pressure relief equipment. Fragments of metal can be ejected through the air.

Transport tanks and pressure receptacles should be removed from the immediate fire area, if this can be achieved without risk to personnel. If this is not possible, the concerned equipment should be immediately cooled with water jets directed from a safe position, for example, from behind heavy machinery or a solid wall. Avoid water contact with pressure relief valves to avoid freezing the pressure relief valves closed.

If the fire involves any tanks or pressure receptacles, it shall be fought from a safe position or by using unmanned water monitors. Water cooling of the equipment should be continued after the fire has been extinguished. Retreat immediately if the pressure relief equipment emits a hissing sound or discoloration of the tank or pressure receptacle is observed. Consider initial evacuation around an 800 m (2600 ft) perimeter. See *Emergency Response Guidebook* [4].

In the event of a fire in the area containing cylinders or bundles of nitrous oxide, EIGA SI 02 *Handling of gas cylinders during and after exposure to heat or fire* should be followed [73].

9.4 Procedures at a traffic incident involving a transport tank

The actions required in the event of a traffic incident involving nitrous oxide transport tanks depend on the circumstances.

The following is given as guidance only regarding the type of action that could be required from drivers.

Where practicable, company guidance should be obtained before any major action is taken and co-operation with the police and other emergency services shall be given at all times.

9.4.1 In the event of breakdown

- If a stop is required on the roadside due to a breakdown, look for a parking area as far away as possible from built-up areas;

- Stop the engine and switch on hazard warning lights. Put on your high visibility clothing. Place warning signs on the road;

- If the position of the vehicle is likely to cause a serious traffic hazard or obstruction, notify the police or traffic authorities; and

- Report to the company for instructions regarding further actions required such as arrangements for assistance with repairs, changes of tractor, or transferring the product from the transport tank to another vehicle.

9.4.2 In the event of an incident

- If involved in an incident, stay calm and give first aid, if possible;

- Stop the engine and switch on hazard warning lights. Put on your high visibility clothing. Place warning signs on the road;

- Avoid open flames. Do not smoke;

- Notify the police and, if necessary, other emergency services such as fire or medical;

- Keep bystanders at a distance and report to the company; and

- Frequently check transport tank pressure and, if necessary, vent nitrous oxide gas to the atmosphere in order to reduce the pressure to less than the maximum allowable pressure. Find a safe place for venting and take precautions to prevent fire hazards.

9.4.3 In the event of leak or spill

- In the event of minor leaks, whenever possible and if no hazards are involved, check and close any valves to isolate the point of leakage;

- If there seems to be no damage to the nitrous oxide tank or pipework that could develop into more serious failures, report to the company and, unless instructed otherwise, drive transport tank to the nearest company premises. Check tank pressure regularly during the journey;

- If leakage appears to be increasing, stop in a suitable place away from built-up areas, and proceed as follows for major leaks;

- In the event of major leaks, where a release can come in contact with the tractor engine, pull to the side of the road, immediately shutoff the engine, and exit the vehicle keeping all personnel away until the emergency services arrive; and

- Notify the police and, if necessary, other emergency services and inform them about the nature of the leak. Report the situation to the company. Stay in attendance throughout any discharge of nitrous oxide. Warn others of danger, ensure no one in the vicinity is working in cellars, basements or trenches, and consider initial downwind evacuation for at least 500 m (1640 ft).

9.4.4 In the event of transport tank overturning

If a transport tank overturns or is lying on its side, it may not be possible to vent gas from either the liquid valve or the gas valve. Follow the company’s emergency response plan and notify the police, and if necessary, other emergency services and inform them about the nature of the incident.

9.4.5 In the event of fire

- If the transport tank is involved in a fire, notify the police and emergency services and report the situation to the company;

- The company should assist emergency responders by providing information about the hazards and properties of nitrous oxide; and

- Be aware of explosive decomposition hazards.

9.5 Personal protective equipment

The following personal protective equipment (PPE) is recommended for emergency responders:

- Firefighters protective clothing is only required for fire situations; it is not effective in spill situations;

- Use self-contained breathing apparatus (SCBA) or supplied air respiratory protection while extinguishing fires, as fire in the presence of nitrous oxide can generate asphyxiating, irritating, and/or toxic gases;

- In the event of minor leakage, wear head protection, safety goggles, gloves, and safety shoes. Ensure that the area is ventilated to reduce the concentration of nitrous oxide; and

- In the event of major leakage, wear thermal protective clothing, face shields, cryogenic gloves, safety shoes, and SCBA or supplied air respiratory protection.

Additional guidance can be found in EIGA Doc 136, *Selection of Personal Protective Equipment* [74].

9.6 First aid

9.6.1 In the event of inhalation of nitrous oxide

- Move the victim to fresh air and call emergency medical services;

- Administer oxygen if the victim is experiencing difficulty with breathing; and

- Perform artificial respiration if the victim is not breathing.

9.6.2 In the event of contact with liquid nitrous oxide

- Remove and isolate contaminated clothing and shoes.

- Clothing frozen to the skin should be thawed before being removed. Do not rub the area. Immerse in warm water (38 °C to 41 °C [100 °F to 105 °F]). Keep the victim warm and calm and seek medical attention;

- Ensure that medical personnel are aware of the product involved and take precautions to protect themselves.

9.6.3 Ingestion of liquid nitrous oxide

Ingestion is not considered a potential route of exposure for liquid nitrous oxide.

10. References

Unless otherwise specified the latest edition shall apply.

[1] EIGA Doc 175, *Safe Practices for The Production of Nitrous Oxide from Ammonium Nitrate,* European Industrial Gases Association. www.eiga.eu

NOTE This publication is part of an international programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[2] *United Nations Recommendations on the Transport of Dangerous Goods - Model Regulations,* United Nations Economic Commission for Europe. www.unece.org

[3] *Gas Encyclopedia*, L'Air Liquide. encyclopedia.airliquide.com

[4] *Emergency Response Guidebook,* U.S. Government Printing Office. www.gpo.gov

[5] ISO 10156, *Gas cylinders - Gases and gas mixtures - Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets,* International Organization for Standardization. www.iso.org

[6] Directive 96/61/EC, *Integrated Pollution Prevention and Control,* European Environment Agency. www.eea.europa.eu

[7] Directive 2003/87/EC, *Establishing a scheme for greenhouse gas emission allowance trading within the Community,* European Commission. https://ec.europa.eu

[8] Lewis, G.D., *Explosion and fire in nitrous oxide tank,* Pratt & Whitney Aircraft. www.pw.utc.com .

[9] Rhodes, G.W. *Investigation of Decomposition Characteristics of Gaseous and Liquid Nitrous Oxide*. AWFL-TR-73-299, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, July 1974.

[10] Krisjansons, J.O., Bollinger, L.E., and Edse, R., *Explosion limit studies of nitrous oxide and nitrous oxide-nitrogen-air mixtures to 200 Atm. and 1800 °R,* Defense Technical Information Center. http://www.dtic.mil/dtic/tr/fulltext/u2/291701.pdf

[11] *TLVs and BEIs Threshold Limit Values for Chemical Substances and Physical Agents and Biologicals Exposure Indices,* American Conference of Governmental Industrial Hygienists. www.acgih.org

[12] *Overview of Greenhouse Gases: Nitrous Oxide Emissions,* U.S. Environmental Protection Agency. www.epa.gov

[13] Directive 2003/105/EC, *The Seveso Directive-Prevention, preparedness and response,* European Commission. http://ec.europa.eu

[14] *Emergency Planning and Community Right-to-Know Act* (EPCRA), *Superfund Amendments and Reauthorization Act (SARA)*, U.S. Environmental Protection Agency. www.epa.gov

[15] EIGA Doc 922, *Site Security*, European Industrial Gases Association. www.eiga.eu

[16] CGA P-50, *Site Security Standard*, Compressed Gas Association, Inc. www.cganet.com

[17] EIGA Doc 913, *Transport Security Guidance for EIGA Members,* European Industrial Gases Association. www.eiga.eu

[18] EIGA Doc 920, *Guidance for Qualifying Customers Purchasing Compressed Gases*, European Industrial Gases Association. www.eiga.eu

[19] CGA P-51, *Transportation Security Standard for the Compressed Gas Industry*. Compressed Gas Association, Inc. www.cganet.com

[20] CGA P-52, *Security Standard for Qualifying Customers Purchasing Compressed Gases*, Compressed Gas Association, Inc. www.cganet.com

[21] EIGA Doc 159, *Reciprocating Cryogenic Pumps And Pump Installations*, European Industrial Gases Association. www.eiga.eu

NOTE This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[22] ISO 11114-1, *Gas cylinders - Compatibility of cylinder and valve materials with gas contents-Part 1: Metallic materials,* International Organization for Standardization*.* www.iso.org

[23] ISO 11114-2, *Gas cylinders - Compatibility of cylinder and valve materials with gas contents-Part 2: Non-metallic materials,* International Organization for Standardization. www.iso.org

[24] EIGA Doc 73, *Design Considerations to Mitigate the Potential Risks of Toxicity When Using Non-Metallic Materials in High Pressure Oxygen Breathing Systems,* European Industrial Gases Association. www.eiga.eu

NOTE This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[25] CGA V-9, *Compressed Gas Association Standard for Compressed Gas Cylinder Valves*, Compressed Gas Association, Inc. www.cganet.com

[26] ISO 21011, *Cryogenic vessels - Valves for cryogenic service,* International Organization for Standardization. www.iso.org

[27] ISO 21010, *Cryogenic vessels - Gas/material compatibility,* International Organization for Standardization*.* www.iso.org

[28] EIGA Doc 13, *Oxygen Pipeline and Pipeline Systems*, European Industrial Gases Association. www.eiga.eu

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[29] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service,* European Industrial Gases Association. www.eiga.eu

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[31] ISO 11621, *Gas cylinders - Procedures for change of gas service,* European Industrial Gases Association. www.eiga.eu

[32] CGA C-10, *Guidelines to Prepare Cylinders and Tubes for Gas Service and Changes in Gas Service*, Compressed Gas Association, Inc. www.cganet.com

[33] EIGA Doc 40, *Work Permit Systems*, European Industrial Gases Association. www.eiga.eu

[34] Directive 2014/34/EU, *Equipment and protective systems for use in potentially explosive atmospheres (ATEX),* European Commission. http://ec.europa.eu

[35] NFPA 70®, *National Electrical Code®*, National Fire Protection Association. www.nfpa.org

[36] CSA C22.1, *Canadian Electrical Code,* Canadian Standards Association. www.csagroup.org

[37] EIGA Doc 51, *Management of Change*, European Industrial Gases Association. www.eiga.eu

[38] EIGA Doc 39, *The safe Preparation of Gas Mixtures*, European Industrial Gases Association. www.eiga.eu

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[39] EIGA Doc 139, *Safe Preparation of Compressed Oxidant-Fuel Gas Mixtures in Cylinders,* European Industrial Gases Association. www.eiga.eu

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[40] ISO 21009-1, *Cryogenic vessels - Static vacuum-insulated vessels-Part 1: Design, fabrication, inspection and tests*, International Organization for Standardization. www.iso.org

[41] CGA G-8.1, *Standard for Nitrous Oxide Systems at Customers Sites,* Compressed Gas Association, Inc. www.cganet.com

[42] EIGA Doc 224, *Static Vacuum Insulated Cryogenic Vessels Operation and Inspection*, European Industrial Gases Association. www.eiga.eu

[43] CGA G-6.12, *Standard for the Suitability of Carbon Steel Containers for Stationary Carbon Dioxide Storage (Formerly PS-5)*, Compressed Gas Association, Inc. www.cganet.com

[44] EIGA Doc 83, *Recommendations for Safe Filling of CO2 Cylinders And Bundles,* European Industrial Gases Association. www.eiga.eu

[45] EIGA Doc 151, *Prevention of Excessive Pressure During Filling of Cryogenic Vessels,* European Industrial Gases Association. www.eiga.eu

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[46] EIGA Doc 24, *Vacuum Insulated Cryogenic Storage Tank Systems Pressure Protection Devices*, European Industrial Gases Association. www.eiga.eu

[47] ISO 21013-1, *Cryogenic vessels – Pressure-relief accessories for cryogenic service-Part 1: Reclosable pressure-relief valves,* International Organization for Standardization. www.iso.org

[48] CGA S-1.2, *Pressure Relief Device Standards—Part 2—Portable Containers for Compressed Gases,* Compressed Gas Association, Inc. www.cganet.com

[49] CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases*, Compressed Gas Association, Inc. www.cganet.com

[50] CGA SB-34, *Product Migration in Manifolded Cylinders Due to Temperature Variations,* Compressed Gas Association, Inc. www.cganet.com

[51] ISO 10961, *Gas cylinders - Cylinder bundles – Design, manufacture, testing and inspection,* International Organization for Standardization. www.iso.org

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[54] *Transportation of Dangerous Good Regulations,* Transport Canada. www.tc.gc.ca

[55] ISO 20421-1, *Cryogenic vessels - Large transportable vacuum-insulated vessels – Part 1: Design, fabrication, inspection and testing.* www.iso.org

[56] ISO 20421-2, *Cryogenic vessels - Large transportable vacuum-insulated vessels - Part 2: Operational requirements,* International Organization for Standardization. www.iso.org

[57] EN 14398-1, *Cryogenic vessels - Large transportable non-vacuum insulated vessels - Part 1: Fundamental requirements,* European Committee for Standardization. www.cen.eu

[58] EN 14398-2, *Cryogenic vessels - Large transportable non-vacuum insulated vessels - Part 2: Design, fabrication, inspection and testing,* European Committee for Standardization. www.cen.eu

[59] EN 14398-3, *Cryogenic vessels large transportable non-vacuum insulated vessels Part 3: Operational Requirements,* European Committee for Standardization. www.cen.eu

[60] *International Maritime Dangerous Goods (IMDG) Code,* International Maritime Organization. www.imo.org

[61] EN 1251-2, *Cryogenic vessels. Transportable vacuum insulated vessels of not more than 1000 litres volume. Design, fabrication, inspection and testing,* European Committee for Standardization. www.cen.eu

[62] ISO 21029-2, *Cryogenic vessels - Transportable vacuum insulated vessels of not more than 1 000 litres volume - Part 2: Operational requirements,* International Organization for Standardization. www.iso.org

[63] EIGA Doc 148, *Installation Guide for Stationary Electric-Motor-Driven Centrifugal Liquid Oxygen Pumps,* European Industrial Gases Association. www.eiga.eu

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