

Nitric Oxide is a compressed gas that is highly toxic as well as a powerful oxidizer

Nitric Oxide, NO

CAS# 10102-43-9

UN# 1660

Molecular Weight: 30

Compressed Gas with a fill limit of 500 psig @ 70°F (21°C)

Gas Density of 0.0777 lb/ft<sup>3</sup>, 1.245 gm/l @ 70°F (21°C)

Above critical temperature at room temperature

Highly Toxic Gas with PEL of 25 ppm, LC<sub>50</sub> of 115 ppm, IDLH of 100 ppm

Shipping Labels Toxic Gas, Corrosive and Oxidizer

Boiling Point, 1 atm. -241°F (-152°C)

Freezing Point, 1 atm. -263°F (-164°C)

Critical Temperature -135°F (-93°C)

While NO is a highly toxic gas, it has been used effectively at low concentrations to treat respiratory problem with newborns and seniors for many years by INO Therapeutics now Ikara



Treatment is

1. 20 ppm for a maximum of 24 hours, followed by 5 ppm for a limited duration of no more than 96 hours
2. In babies with HRF, blood vessels in the lungs constrict, making it difficult for the heart to pump blood through the lungs for oxygenation. INOmax<sup>®</sup> is a selective pulmonary vasodilator, which



relaxes the blood vessels of the lungs in newborns whose heart and lungs could not otherwise carry enough oxygenated blood to the body tissues. INOmax® improves oxygenation

3. Nitric oxide is a critical signal molecule in the nervous system, a weapon against infections, and a regulator of blood pressure and flow

With COVID 19 "The cardiopulmonary benefit demonstrated by INOpulse in various indications provides the potential to prevent deterioration in patients with COVID-19, allowing ventilators to be preserved for the most critically ill. INOpulse's ease of administration could significantly decrease the burden on therapists and nurses," said the treating physician, Roger Alvarez, Assistant Professor, University of Miami School of Medicine.

Nitric Oxide is also used in Semiconductor chip manufacturing to deposit a gate oxide (Silicon Oxynitride:  $\text{SiO}_x\text{N}_y$ )

#### Manufacture

1.  $\text{NH}_3 + \text{O}_2 \rightarrow \text{NO} + \text{H}_2\text{O}$  exothermic reaction.
2.  $\text{N}_2\text{O}_4$  and reacted it with  $\text{H}_2\text{O}$ :  
 $1.5\text{N}_2\text{O}_4 + \text{H}_2\text{O} \rightarrow \text{NO} + 2\text{HNO}_3$
3. Reaction of Nitric Acid and Sulfur Dioxide in presence of water  
 $3\text{SO}_2 + 2\text{HNO}_3 + 2\text{H}_2\text{O} \rightarrow 3\text{H}_2\text{SO}_4 + 2\text{NO}$

When released into air it oxidizes to form  $\text{NO}_2$ . Red gas



$\text{NO}$  and  $\text{NO}_2$  causes rapid olfactory fatigue. Pulmonary edema could be delayed up to 72 hours.

#### Incidents

At the Matheson Nitric Oxide manufacturing facility in East Rutherford, NJ facility lecture bottles of  $\text{NO}$  were filled directly from a source cylinder pressurized to 800 psig. On Feb 1, 1963 when the valve to the 44 liter source cylinder was opened it violently ruptured killing the operator. The investigation determined that the lecture bottle valve was not open which caused the gas in the small volume of the manifold to heat up significantly from the rapid adiabatic compression. This may have ignited some oil



contamination in the valve/line. This was enough energy for the Nitric Oxide decomposition to be initiated. It propagated back into the source cylinder, rupturing it into 4 pieces.

The Matheson investigation highlighted DuPont test data that reported theoretical decomposition of Nitric Oxide can cause a 15 fold increase in pressure. The decomposition reaction however requires significant energy to initiate it. A blasting cap triggered the decomposition in a test cylinder which had a 12 fold pressure increase. At the 800 psig fill pressure the final pressure in the source cylinder may have reached 9600 psig.

As a result of this incident, Matheson reduced the cylinder fill pressure to 500 psig (max decomposition pressure of 6000 psig). With one exception, the other gas suppliers have followed this limitation.

On Oct 9, 1972, Big Three Industries (now Air Liquide) had a similar incident except at a considerably lower pressure of 200 psig. The cylinder and the system were able to contain the resulting pressure of 2400 psig.

In 2004, the gas industry forgot about the voluntary fill limit that had been established by the compressed gas industry after the 1963 incidents and supported an increase in fill density beyond 500 psig. I wrote a letter to CGA on July 7, 2005 to Bill Heintz, Chairman Specialty Gases Committee and Mike Injaian, Chairman Task Force 00-69, Subject: Fill Density for Germane and Nitric Oxide summarizing the incidents and the gas industry voluntary reduction in fill density to 500 psig.

#### **Liquid NO**

Los Alamos National Labs (LANL) developed a cryogenic NO distillation system. They ran it from 1960's to late 1970's. They had a small explosion in 1975 of liquid/solid NO.

The US Bureau of Mines investigation determined that "liquid NO is comparable to nitroglycerin in sensitivity to weak shock waves"<sup>1</sup>

Liquid NO can explode at its boiling point  $-241^{\circ}\text{F}$  ( $-152^{\circ}\text{C}$ )<sup>2</sup>

Nitric Oxide distillation Explosion Isotec, Sept 21, 2003. (CSB Investigation) Leak into the vacuum jacket occurred twice before in 1995 and 1998. Never determined root cause.

On Sunday, September 21, 2003, at about 7:30 am, the Isotec on-call system operator received an automatic pager alert indicating an alarm condition in a cryogenic nitric oxide (NO) distillation unit. Arriving at the facility at about 7:50 am, he observed reddish-brown gas venting from the distillation unit vacuum pump exhaust—which indicated a breach in the column piping within the vacuum jacket. At 8:15 AM the vacuum pump suction valve was shutoff. They installed a temporary line to vent the system which stabilized at 130 psig. Condenser LIN was boiling off rapidly. Suddenly at 10:15 the system violently exploded.<sup>3</sup>

## Figure 1

20-foot-diameter, 8-foot-deep crater and structural damage caused by NO process unit explosion



NO and NO<sub>2</sub>, Delayed Pulmonary Edema

### Theory

NO is different than other unstable gases. It has an unpaired electron in an antibonding orbital that might be quite important in promoting the association of NO molecules in the condensed phase creating a more facile (little effort) initiation of the decomposition reaction.

In liquid and solid form, nitric oxide is an unpredictable, highly shocksensitive explosive. System design and operating procedures to minimize the possibility of liquid NO detonation are not well understood. Passive controls were used in the Isotec to minimize the effects of an explosion

The portion of the column installed in the well casing below ground to accommodate its extreme length provided a high level “shielding.” The exterior blast shield structure (Figure 8)—installed in response to similar LANL upgrades—was intended to protect employees and equipment in the unlikely event of an NO detonation in the aboveground equipment.

The exterior blast containment structure was an open-top, four-wall rectangular carbon steel plate configuration. Each wall was fabricated using two unreinforced 0.5-inch-thick plates spaced about 4 inches apart. The gap between the plates was filled with sand; the wall panels were welded at the corner joints using structural steel angle shapes.

The Isotec structure however omitted two key safety features of the LANL design:

1. A heavy steel wire mesh top to capture debris.
2. A wide top-to-bottom labyrinth opening in one wall to prevent pressure buildup



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## References:

1. Ribovich, J., Murphy, J. and Watson, R. "Detonation studies with nitric oxide, nitrous oxide, nitrogen tetroxide, carbon monoxide, and ethylene", Journal of Hazardous Materials, Volume 1, Issue 4, 1975-1976, Pages 275-287
2. Miller, Riley O. "Explosions In Condensed Phase Nitric Oxide" I&EC Process Design and Development, 1968, 7 (4), pp 590-593
3. EXPLOSION AT BIOCHEMICAL FACILITY: LIQUID NITRIC OXIDE RELEASE, ISOTEC, a wholly owned subsidiary of Sigma-Aldrich Corporation, Miami Township, Ohio, Chemical Safety Board Report, September 21, 2003

