SCALED COMPOSITES, LLC

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Scaled Composites Safety Guidelines for N_2O

Background:

Scaled Composites shares this information in order to help facilitate the industry's use of N_2O as a rocket motor oxidizer in as safe a manner as practical. Scaled bases this set of guidelines on our experience using N_2O and research into other organization's usage and testing. Do not consider this an exhaustive or complete list.

Although generally available from public documents, Scaled Composites does not believe this information has been previously collected into a single source and hopes that others may find it useful.

Scaled's Requirements for N_2O Systems:

1. **Ignition Sources:**

   Review any and all movable parts (valves, regulators, etc.) in the N_2O oxidizer flow path for potential sources of energy release into the oxidizer. Numerous potential sources of ignition exist, including, but not restricted to:

   a) Friction (metal on metal, plastic on metal, plastic on plastic, etc.)
   b) Static discharge/sparking
   c) Impact

   Design all components and assemblies so that they are incapable of releasing any substantial amount of energy into the oxidizer. No component or assembly should be capable of producing a temperature, for any length of time, on any surface, above 573 deg K (571 deg F).

   Put substantial effort into reviewing what will occur if, for any reason, any component of the N_2O oxidizer flow path ever does reach this temperature threshold.

2. Adiabatic Compression:

Designs should attempt to minimize adiabatic compression in the system during flow of the N_2O oxidizer. This implies controlling the rates of valve openings (similar to LOX system design), and minimizing dead volumes down stream of valves. Adiabatic compression alone has low effectivity in starting a decomposition reaction; however, the presence of contaminants or incompatible materials that can act as fuels may reduce the ignition threshold of N_2O to the point where adiabatic compression in an otherwise adequate system can begin a reaction.

3. Compatibility Testing:

No significant body of materials compatibility test data for N_2O in aerospace applications exists, so the design process should plan for ensuring compatibility of all materials exposed to the N_2O oxidizer.

For compatibility testing of materials you may consider for a N_2O flow path, standard LOX impact sensitivity tests such as those described by ASTM G36 or NASA STD-6001 Method 13 are useful. However, the test method should be modified to include soaking the materials in N_2O before test.

Experience has shown that some materials such as silicone (which is generally considered N_2O compatible) absorb N_2O. The N_2O saturated silicone exhibits impact sensitivity, whereas the raw material does not.

Also, some materials may outgas a combustible product when exposed to N_2O. This out gassing may be facilitated by the fact that liquid N_2O is a very good solvent and is even more capable of dissolving organic compounds than liquid CO_2, which is well known for its solvent properties.

We have shown with hot wire fixed volume ruggedized “bomb” vessel ignition testing that the presence of these gases can significantly reduce the ignition threshold (by a factor of 5), and increase the yield and rate of the resulting decomposition reaction. Therefore, compatibility testing may need to include ignition testing.

Compatibility testing should include, but should not be restricted to, elastomers, plastics, metals and lubricants. This is not an exhaustive list, but is only indicative of the wide range of materials that must be considered for compatibility.

4. Incompatible Material Removal:

As a corollary to #3, remove all incompatible materials from the N_2O oxidizer flow path and/or storage.

5. Corrosion-Prone Metals:

Related to items #3 and #4, remove all corrosion prone metals (non-stainless steels, etc.) from the N_2O oxidizer flow path and/or storage, due to risk of catalytic reaction.

6. Decomposition in Liquid:

N_2O is extremely resistant to decomposition in pure liquid form. However, combustion/decomposition in the liquid form can occur if sufficient fuel exists to propagate the reaction. Organic materials such as epoxy composites combust more readily than metals such as stainless steels. Therefore, using metallic materials in the oxidizer flow system will increase the tolerance of the system to fuel contaminated liquid combustion/decomposition and reduce potential for fuel contamination.

Also, the system pressure significantly affects the ignition sensitivity of liquid N_2O. For example, N_2O flowing at 130 psi in an epoxy composite pipe would not react even with a 2500 J ignition energy input. However, at 600 psi, the required ignition energy was only 6 J.

7. Decomposition in Gas:

N_2O is less stable as a gas in comparison with its liquid form and so consideration should be given to minimizing the potential for decomposition of the gas.

Previous testing such as discussed in the Air Force Weapons Lab report AFWL-TR-75-231 showed that Helium diluent can reduce the possibility of decomposition of N_2O when used in sufficient quantity. Additional testing confirms that a diluent gas (such as He or N_2) can increase the required ignition energy and reduce the yield of any decomposition reaction. It may be possible to eliminate decomposition progression in N_2O gas with enough diluent concentration, and this should be evaluated for the system being studied.

Minimizing the quantity of gaseous N_2O and/or two phase flow in the oxidizer flow path via a pressurant/diluent system should be considered.

8. Oxidizer Flow Path Design:

Ensure that the N_2O flow path does not have eddies or stagnation zones due to sudden changes in flow path cross section. These can act as "flame holders" and prevent the flow from displacing any decomposition reaction downstream.

Testing of the oxidizer flow path in combination with an ignition event should be performed to ensure that decomposition cannot persist anywhere in the flow path.

9. Pressure Vessel Design:

In the event that ignition prevention measures and deflagration wave mitigations fail, pressure vessel designs should allow for a controlled failure upon overpressure. In large oxidizer systems operated at high pressures, the energy released during a tank rupture for what ever reason (structural, overpressure, feedback, decomposition) is very high. This failure mode should be designed for with burst disk or other similar safety precautions that can safely reduce the PV energy in the vessel without catastrophic failure.

10. Cleaning Procedures:

Since there is such a small body of data available on materials compatibility with N_2O and the definition of "significant" contamination levels, industry-standard procedures for handling aerospace oxidizers such as LOX should be considered with respect to all materials that come in contact with the oxidizer.

11. Test Safety:

Test safety procedures should always consider worst-case scenarios when planning safe distances for participants during development testing. For example, the NASA Glenn Research Center Safety manual has methods for setting safe distances during pneumatic tests. The distances are calculated such that the overpressure due to rupture does not exceed 0.5 psi at the personnel location. Take additional precautions for the debris field that this sort of energy release may create, which may exceed the distance required for overpressure alone.

Additional References:

1. “Nitrous Oxide Explosive Hazards”, Claude Merrill, AFRL, May 2008, unlimited distribution

2. “Summary of Nitrous Oxide Investigations”, AFWL, July 1976, unlimited distribution

3. “Storage and Use of Nitrous Oxide - The Nitrous Oxide Decomposition Reaction”,

   L. Martin Tupman, Puritan-Bennet Corporation, 1994 CGA Seminar

4. “Explosion Limit Studies of Nitrous Oxide and Nitrous Oxide-Nitrogen- Air Mixtures to 200 ATM. and 1800 deg R”, Juris O. Krisjansons et. al., OSU & ARL Office of Aerospace Research, September 1962

5. “Investigation of Decomposition Characteristics of Gaseous and Liquid Nitrous Oxide”, Captain G. W. Rhodes, AFWL, July 1974, unclassified

6. “Modeling of N_2O Decomposition Events”, M.A. Karabeyoglu, J. Dyer, J. Stevens and B. Cantwell, AIAA-2008-4933, AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Hartford, CT, July 21-23,2008