Is nitrous oxide safe?

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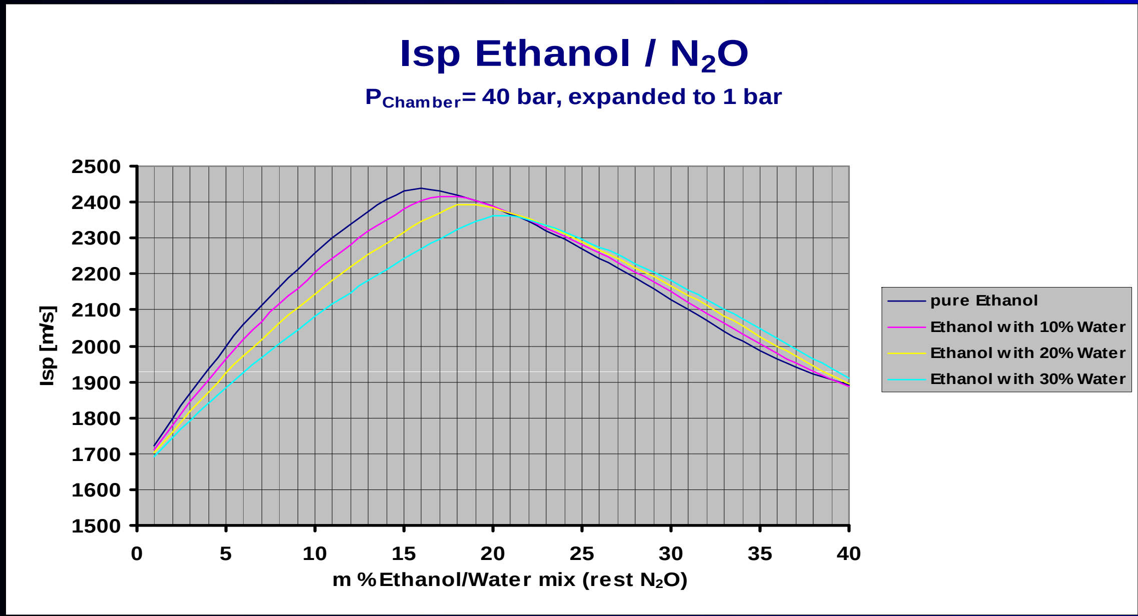
5. October 07, Bruno Berger SPL, www.spl.ch

N_2O for Rocket propulsion

Pros...

- Good availability (Car-Tuning, Gas-vendors)
- Self pressurizing (Vapor pressure at 20°C is ~50.1 bar)
- Nontoxic, low reactivity ➔ rel. safe handling (General safe ???)
- Additional energy from decomposition (as a monopropellant: ISP of 170 s)

- Specific impulse doesn't change much with O/F



N_2O for Rocket propulsion

Cons...

- Unnecessary high pressures. Only storable in high pressure bottles or under sub cooled conditions. Draining and reuse normally not applicable: Wasted propellant
- Low density (Liquid phase: 750 kg/m^3 at 20°C), lousy density-ISP
- Expensive (>20x as much as LOX)
- Strong dependency of pressure from temperature (At a hot day is can even be supercritical)
- N_2O is a strong greenhouse gas
- Mass flow difficult to measure (2-phase flow)
- Rel. high mass fraction in the residual gas phase (after depleting the liquid) which is often of low usefulness
- N_2O is a monopropellant (as H_2O_2 or Hydrazine. Risk of runaway reaction, see following slides) 
- Saturated fluid (small pressure- and temperature changes ➔ boiling ➔ cavitation ➔ imploding bubbles) 

Incidents

Explosion at Scaled Composites (Constructor of the Spaceship 1 & 2)

- 3 persons killed
- Cold flow test of the injector of a hybrid motor (no grain was installed, no combustion test!)
- Heavy burns of the casualties (➔ decomposed N_2O, so injuries not only from stored pressure energy in the vessel)
- Trigger still unknown (Oct. 07). Guess: water hammering caused by cavitation combined with organic contamination (So-called “Dieseling”)

Incidents 2

Explosion N_2O of a tank truck in Eindhoven NL [1]

- Tank truck with 7.5 metric tons of sub cooled N_2O (rel. low pressure)
- Result of the investigation: A not pre cooled centrifugal pump was running hot and started decomposition of the nitrous oxide. N_2O at > 5.7 bar and a present ignition source can start a runaway reaction [2]. Flashback into the tank.

Incidents 3

Explosion of a N_2O hybrid motor (Flashback) [3]

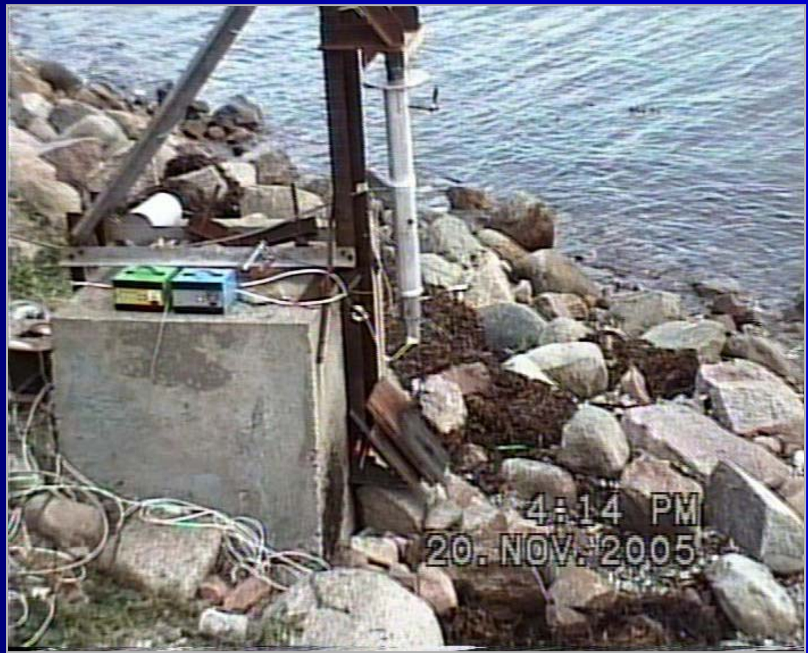
- To low Δp over the injector ➔ Combustion instabilities ➔ pushing back combustion gases into the nitrous tank.
- Following decomposition of the nitrous oxide
- Movie (Thanks to Troy Prideaux)

Incidents 4

Explosion N_2O / alcohol engine (Flashback) [4]

- Design flaw of the Injector caused a contamination of the N_2O channels with alcohol. „Water hammering" in the N_2O ignited the mixture and destroyed injector and valves.

  Movie (Tanks to Henrik Schulz from DARK)



Potential risks

- N_2O is normally used under saturated condition: 2-phase flow with high potential of water hammering ➔ adiabatic compression of cavitation bubbles ➔ "Dieseling" specially when contaminated with fuel and at combustible surfaces like seals, filling hoses, carbon fiber tanks etc.)

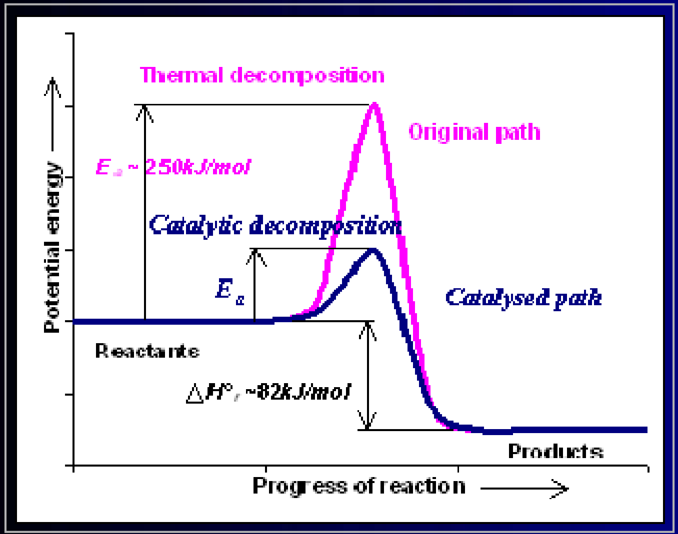
Imploding vapor bubble with jet (up to 100000 bar at the ground of the jet and temperatures of several thousand K !)

$\frac{p_G}{p_N}$ [-]	$p_{i\,max}\left[\frac{N}{mm^2}\right]$	$T_{i\,max}$ [K]
0,1	1,3	610
0,05	7,2	990
0,01	405	3140
0,005	2290	5160

Potential risks 2

N$_2$O is a monopropellant (as H$_2$O$_2$ or Hydrazine)!

- Under certain conditions more energy is produced by the decomposition than necessary to reach the decomposition temperature ➔ run away reaction!
  $N_2O(g) \longrightarrow N_2(g) + \frac{1}{2}O_2(g) + 82\ kJ/mol$
- Particularly the vapor phase can lead to a deflagration or even a detonation at pressures > 5.7 bar if a contamination of fuel is present
- Catalysts can lower the critical temperature to 250 °C (E.g. copper and its oxides)



Potential risks 2

- Very good solubility in oil, grease and other hydrocarbons like plastics etc. (That's why it works so well for whipped cream). Also solid plastics like HTPB or fiber reinforced plastics can be saturated when exposed to nitrous oxide for a long period and can then transform to a high explosive.
- According to several sources, electro static discharge during injection into a combustion chamber can occur. Combined with the point above this can lead to an unexpected disassembling of the engine.
- Freezing of valves and venting orifices.
- Unknown Voodoo [5]:

d. Anomalies

One disturbing observation during the gaseous test program was the rather frequent (about 10 percent of the tests) occurrence of unexplained events in two categories, spontaneous ignitions and spontaneous temperature rises. In the first category, sudden temperature and pressure spikes were sometimes observed while N_2O was being vented from the pipe. These anomalies generally occurred at low-pressure conditions where steady-state decomposition cannot be sustained. The other category consisted of unusual increases in pipe wall temperatures (by 20 to 50°F) during filling operations without any sudden pressure rise or other indication of a decomposition reaction. Both of these anomalies remain unexplained.

Suggestions

- Δp over injector > 10 bar. A screaming hybrid is a sign for combustion instabilities and therefore for a too low Δp.
- Only use the liquid phase
- For hybrids: Do not expose the grain to nitrous oxide for a long period (no saturation of the grain). Venting and dumping not through the combustion chamber
- Electr. ground tanks etc.
- NO combustibles materials for seals, hoses (also filling hose) and tanks (e.g. Fiber reinforced ones without metallic liner). Metals (INOX, Alu), PTFE, PCTFE or some Silicones are ok. Viton, FKM, FPM are chemical compatible but are swelling significantly when exposed to N_2O. Avoid copper alloys. Only use compatible lubricants like CRYTOX. Ask your supplier for chemical and physical compatibility with N_2O!
- Stay below the critical diameter in the feeding lines by using some kind of deflagration trap (E.g. a big sintered metallic filter, bundle of tubes etc) [8]
- Use burst disks at the tank.
- Hydro testing the tanks > 100-150 bar.
- Density of N_2O change significantly with temperature. Do not fill the tank completely: 13-15% ullage for a possible temperature increase from 15°C to 25°C [6],[7]

Suggestions

- Remote operated filling and draining. Electrical ground the tanks and filling lines
- Attention after unsuccessful ignition. With N_2O saturated grain or other fuel can be explosive.
- To avoid bubbles and therefore cavitation: Use sub cooled N_2O and pressurize it with N_2 or Helium.
- Use LOX ;-)

- Let me know if you have other suggestions or you think I am paranoid: bruno.berger@spl.ch

Conclusion

Rocket propellants are high energetic materials (That's why we use it) and therefore potential dangerous! As every oxidizer, nitrous oxide has it's vantages but also it's pitfalls. Even N_2O can be handled and operated in a safe way provided you are aware of the risks. This is also true for other oxidizers like LOX, H_2O_2, N_2O_4 and nitric acid etc.

Sources

1. "Nitrous Oxide Trailer Rupture, July 2, 2001" Presentation of Mr. Konrad Munke, Linde Gas AG
2. "Untersuchungen von Zerfallsfähigkeit von Disticksoffoxid", research report 89, Bundesanstalt für Materialprüfung BAM, 1983
3. Pictures and movie from Troy Prideaux
4. Movie Henrik Schulz DARK, http://www.dark.dk/
5. "Investigations of Decomposition Characteristics of gaseous and liquid Nitrous Oxide" by G.W. Rhodes, AD-784 802, Air Force Weapons Laboratory, Kirtland Airforce Base, 1974
6. "Calculation and Verification of Filling Ratios for Liquified Gases DTRS56-02-X-0049" NIST and DOT
7. http://www.aspirespace.org.uk/ (technical papers)
8. Flame Propagation in Gaseous Nitrous Oxide by A. A. Borisova, K. Ya. Troshina, and Yu. S. Biryulinb

Others:

- Catalytic Ignition of Nitrous Oxide With Propane/Propylene Mixtures for Rocket Motors, AIAA 2005-3919
- Catalytic Decomposition of Nitrous Oxide for Spacecraft Propulsion, ADA 392935

Questions ?

Contact and further info‘s:
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