Methods for Decontamination of a Bipropellant Propulsion System

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Introduction

- Most propulsion systems are designed to be filled and flown, draining can be done but decontamination may be difficult
- Transport of these systems may be difficult as well because flight weight vessels are not designed around DOT or UN shipping requirements
- Repairs, failure analysis work or post firing inspections may be difficult or impossible to perform due to the hazards of residual propellants being present

Common Propellants

- Hydrazine
  - Monopropellant and bipropellant uses
  - Soluble in water and alcohols
  - Hydrazine systems have heaters and insulation for freeze protection
  - Toxic ACGIH 10 ppb TLV/TWA
  - Freezing point about 2° C (35° F)
  - Boiling point about 113° C (235° F)
  - Heat capacity 3.08 J/gK
  - Heat of fusion 396 J/g
  - Heat of vaporization 1398 J/g

Common Propellants

- Monomethylhydrazine (MMH)
  - Bipropellant uses
  - Soluble in water and alcohols
  - Toxic ACGIH 10 ppb TLV/TWA
  - Freezing point about -52° C (-62° F)
  - Boiling point about 87° C (189° F)
  - Heat capacity 2.92 J/gK
  - Heat of fusion 226 J/g
  - Heat of vaporization 877J/g

Common Propellants

- Dinitrogen Tetroxide (NTO)
  - Bipropellant oxidizer
  - Reacts with water to make nitric and nitrous acids
  - Soluble in CFC-113
  - Toxic NASA 1.0 ppm PEL
  - Freezing point about -11° C (12° F)
  - Boiling point about 21° C (70° F)
  - Heat capacity 1.55 J/gK
  - Heat of fusion 159 J/g
  - Heat of vaporization 414 J/g

Common Solvents

- Water
  - Non-toxic, non-flammable
  - Freezing point about 0° C (32° F)
  - Boiling point about 100° C (212° F)
  - Heat capacity 4.18 J/gK
  - Heat of fusion 334 J/g
  - Heat of vaporization 2270 J/g

Common Solvents

- Isopropyl alcohol (IPA), 2-propanol
  - Toxic (ACGIH TLV/TWA 200 ppm), flammable
  - Freezing point about -89° C (-128° F)
  - Boiling point about 82° C (181° F)
  - Heat capacity 2.68 J/gK
  - Heat of fusion 88 J/g
  - Heat of vaporization 733 J/g

Common Solvents

- Ethyl alcohol, ethanol
  - Toxic (ACGIH STEL 1000 ppm), flammable
  - May cause issues with titanium alloys
  - Freezing point about -114° C (-173° F)
  - Boiling point about 78° C (173° F)
  - Heat capacity 2.44 J/gK
  - Heat of fusion 107J/g
  - Heat of vaporization 920 J/g

Purge Gases and Materials

- Helium Heat Capacity 1.04 J/gK (0.0012 J/mLK)
- Nitrogen Heat Capacity 5.19 J/gK (0.0008 J/mLK)

- Aluminum Heat Capacity 0.90 J/gK
- Chromium Heat Capacity 0.45 J/gK
- Iron Heat Capacity 0.45 J/gK
- Nickel Heat Capacity 0.44 J/gK
- Titanium Heat Capacity 0.52 J/gK

Soft goods

- This work is focused on returning hardware to a state where it can be reused/flown/tested
- Soft goods functionally never decontaminate
- For a system to be rendered permanently safe in a decontaminated state the soft goods must be removed
- If a solvent is chosen for rinsing, the interaction of the solvent with the soft goods should be understood if the hardware will not be disassembled to replace the soft goods

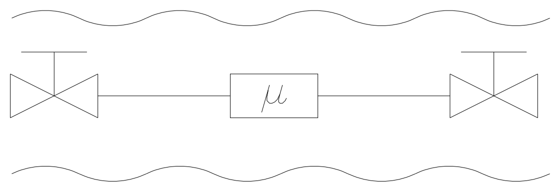
Decontamination Methods

- Solvent Rinsing/flushing
- Advantages
  - Doesn't require propellant to vaporize, no heat required
  - Potentially fast
  - Bureaucratically clean (triple rinsed)
- Disadvantages
  - Requires a flow path (no dead end)
  - Rinsate is likely hazardous waste
  - Introduces something that will ultimately have to be removed
  - May cause corrosion (water rinse of an NTO system)
  - May leave residues less volatile (nitric acid in an NTO system)

Decontamination Methods

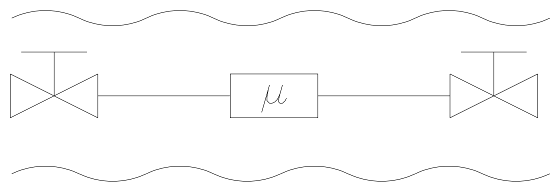
- Gas purging
- Advantages
  - Doesn't introduce something to remove later (inert gas assumed)
  - Purge gases commonly available and possibly interfaced to hardware already
  - Detection methodologies commonly available for gas stream evaluation
- Disadvantages
  - Requires a flow path (no dead end)
  - Purge gas is still hazardous
  - Heat required to convert propellant to a vapor and remove it
  - Hard to put heat into a system with a gas due to low heat capacities of gases

Example Propulsion System Element



- Valve
- Line
- Filter
- Line
- Valve
- Heated and insulated

Decontamination of Element



- First valve may be opened
- Second valve stays closed
- Heater may be turned on
- Insulation may not be removed
- Entire element will need to be in a vacuum to protect the tank

Fluids in a Vacuum

- Vacuum is not the “Magic Bullet”
- More or less assumed to be adiabatic, heat capacities are small compared to heats of vaporization and fusion, lines insulated
- As pressure drops liquid begins to boil, heat of vaporization comes from cooling the liquid and finally from heat of fusion
- Boiling liquid turns into ice (more or less a triple point)
- Under vacuum, diffusion now defines flow
- Filters act as diffusion restrictors
- Once vacuum is achieved, useful decontamination becomes minimal

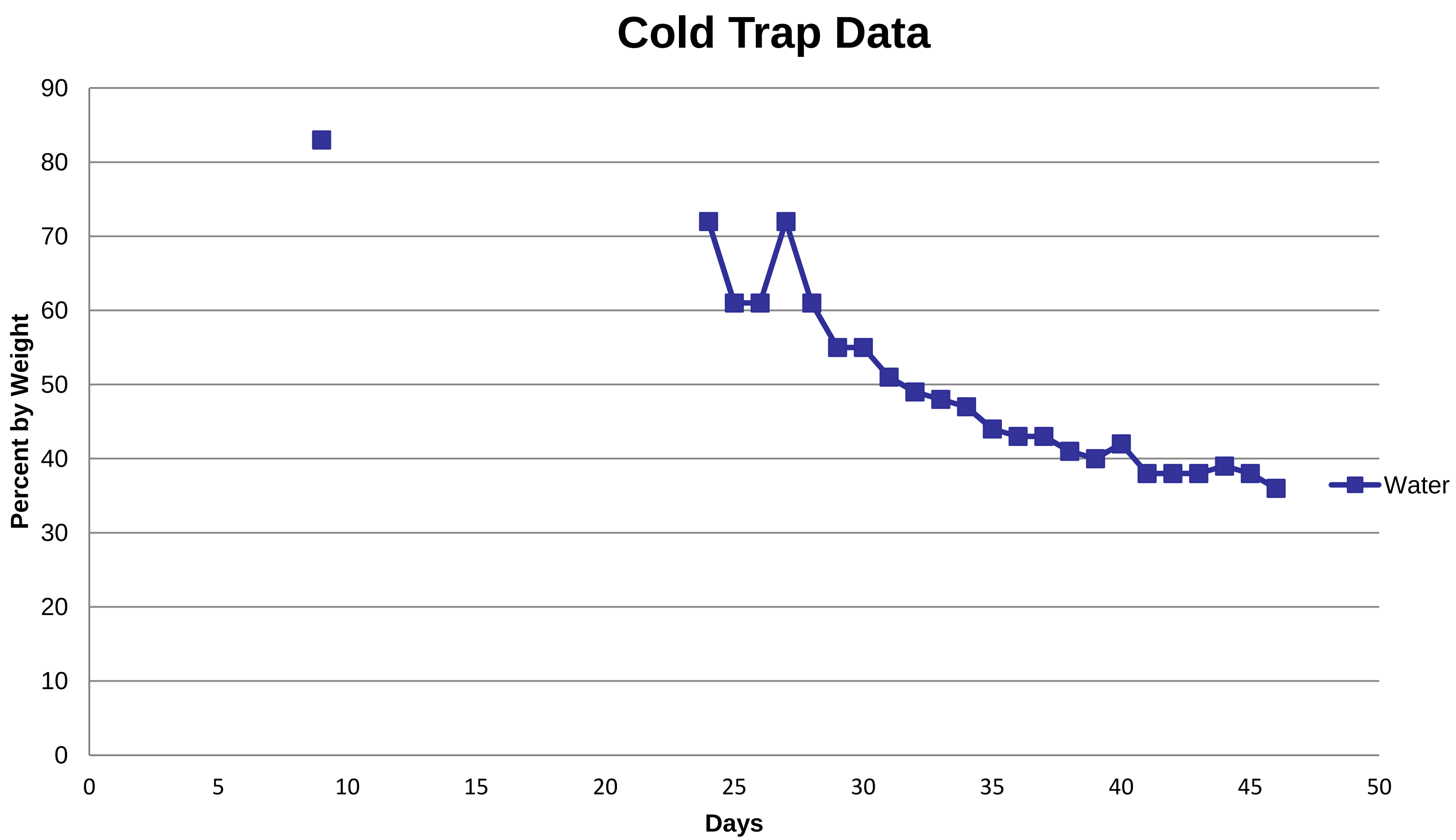
Flow Simulation in a Dead End

- Once vacuum is achieved, system is re-pressurized
- Although this will carry vapor back into the system it is the vehicle to ultimately remove it
- After pressurization, system is vented and a vacuum reapplied
- Each venting and vacuum cycle removes propellant/solvent vapor
- Vapor production is dependent on heat available to vaporize the propellant/solvent

Heat Flow Problems

- Under vacuum it is hard to heat an insulated line
- Line heaters are sized to feed heat capacity not heat of vaporization
- Gas (even warm gas) doesn't really carry much heat into the system
- The lack of heat flow into the system makes this a very slow process

Slow Decontamination Progress



Relevant Work

- Jokela, K., Kälsch, I., ***Decontamination of MMH and NTO/MON Propellant Tanks,*** 4th International Spacecraft Propulsion Conference, June 2004
- Stramaccioni, D., ***The Rosetta Propulsion System,*** 4th International Spacecraft Propulsion Conference, June 2004
- Smith, C., ***All Fuelled Up and No Place to Go, The Rosetta MMH Offload Campaign Kourou 2003,*** 4th International Spacecraft Propulsion Conference, June 2004
- DePasquale, J, Driggs, C., Gaudnagnoli, D, ***Method for Decontamination of a Bipropellant Propulsion System***, 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July 2010
- Greene, B., Mast, D., Maes, M., ***Soft Goods Permeation, Offgassing, and Decontamination Studies with Monomethylhydrazine and MON-3 Nitrogen Tetroxide,*** JANNAF 36th Propellant and Explosives Development Joint Subcommittee Meeting, December 2010

Conclusions

- Solvents should be carefully chosen to avoid problems with contamination, corrosion and removal
- Heat flow (or lack of it) into the system will largely determine the amount of time it will take to decontaminate it
- Vacuum is important but works best if an artificial flow is set up to remove volatilized species
  - Bulk draining (optional and well considered solvent rinse)
  - Pulse purging (maximum safe upper pressure to vacuum)
  - Heat as you can (but recognize that it is hard to do)