Alternative Green Solvents Project

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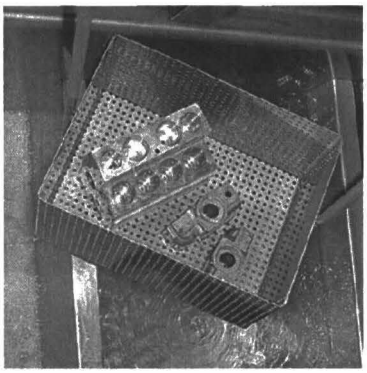
Background

- Necessary for safe and proper functioning of equipment
- Mainly halogenated solvents
  - Carbon tetrachloride
  - Trichloroethylene (TCE)
  - CFC-113
- No longer used due to regulatory/safety concerns

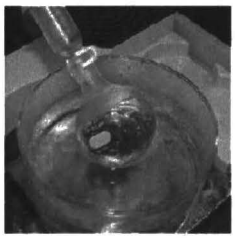
Precision Cleaning at KSC

- Small % of total parts
- Used for liquid oxygen (LOX) systems
- Dual solvent process
  - Vertrel MCA (decafluoropentane (DFP) and *trans*-dichloroethylene)
  - HFE-7100
- DFP has long term environmental concerns



Specifications and Analysis

- Highest level at KSC – 25A
- Verified by particle counting and NVR analysis



Particulate Matter Contamination Levels			NVR Contamination Levels		Visible Contamination Levels	
Level	Particle Size Range µm (micrometer)	Maximum Number of Particles per 0.1 m^2	Level	Maximum NVR (mg/0.1 m^2)	Level	Definition
25	<5 5 to 15 >15 to 25 >25	Unlimited* 19 4 0	A	1.0	GC	Freedom from manufacturing residue, dirt, oil, grease, etc.

Project Goals

- Identify potential replacements
  - 22 wet chemical processes
  - 3 alternative processes
- Develop test procedures
  - Contamination and cleaning
  - Analysis
- Use results to recommend alternative processes

Candidate Process Criteria

- Good solvency
- Low toxicity
- LOX compatible
- Environmentally friendly
- Low surface tension
- High vapor pressure
- Inexpensive

Processes Evaluated

Pure Solvents	Proprietary Solvent Formulations	Alternative Technologies
Acetone, ethanol, cyclohexane, ethyl acetate, isopropyl alcohol, NMP, limonene, ethyl lactate, 1-bromopropane, methyl myristate, tert-butyl acetate	Entron Aero, Citricolv, Inland Isoprep, Inland AV-OP-125, Inland Breakthrough, Inland Skysol, Steposol SB-W, Steposol SB-D, Steposol SC, Steposol M-8-10, Vertec Bio	Atmospheric plasma glow discharge (AGPD), supercritical carbon dioxide ($SCCO_2$), carbon dioxide snow

Candidate Solvents

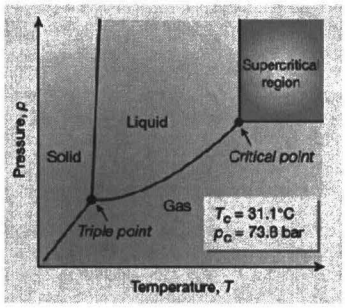
- Easiest to integrate with existing process
- Avoided highly halogenated solvents
- Augmented with sonication, directed pressure, etc.
- May be recycled to reduce waste stream

Plasma Cleaning

- Plasma is an ionized gas (TVs, lightning, etc.)
- Created by applying electrical field to a gas
- Clean via sputtering and/or chemical reaction
- Important parameters: gas type, exposure time, energy

Supercritical CO_2

- Has properties of both liquid and gas
- Exists at temps >31.1°C and pressures >1072 psi
- Dissolves nonpolar molecules and hydrocarbons well
- Cleaning can be enhanced by the use of cosolvents



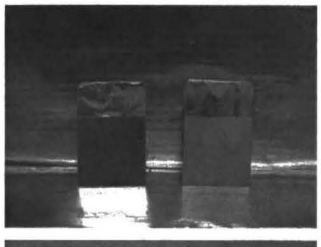
CO_2 Snow

- Cleans via thermo mechanical shock or dissolution
- CO_2 density determines type of cleaning

- Technique is similar to aqueous pressure washing
- Adjustable parameters: nozzle design, velocity, additional propellants

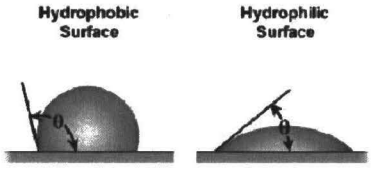
Solvent Testing Method

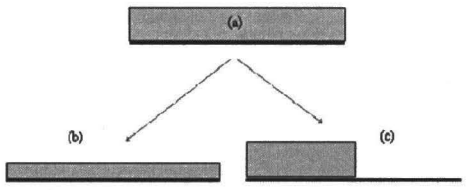
- 2" x 2" Al coupons
- Rough and smooth textures
- Sprayed with 5 contaminants
- Rinsed with 15mL of solvent and dried for one hour or...
- Cleaned by alternative process



Analytical Methods

- Problems w/ NVR
- Gravimetric
- XPS
- Contact angle





Top 5 Solvent Results

Solvent	83282	5606	Dioctyl Sebacate	Krytox	Braycote
Vertrel	102.7	83.3	98.5	98.6	89.0
1-bromo propane	98.4	117.1	101.0	54.9	20.0
T-butyl acetate	99.1	102.5	99.3	54.1	29.2
Ethyl acetate	93.2	77.8	95.5	75.6	33.6
Isopropyl alcohol	100.4	79.0	98.8	66.6	15.6

Values listed are in % cleaning efficiency determined by gravimetric analysis

Contact Angle Measurements for Alternative Technologies

Technology	83282	Krytox	Braycote
Vertrel MCA	88.7°	88.5°	96.5°
Plasma	44.4°	59.6°	79.3°
$SCCO_2$	<10.0°	109.9°	10.0°
CO_2 Snow	91.5°	105.7°	108.8°

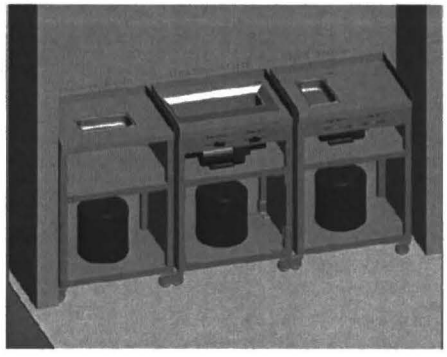
Values listed are in degrees as determined by contact angle measurements

Conclusions

- No alternative matched Vertrel in this study
- No clear second place solvent
- Hydrocarbons – easy; Fluorinated greases – difficult
- Fluorinated component may be needed in replacement solvent
- Process may need to make up for shortcoming of the solvent
- Plasma and $SCCO_2$ warrant further testing

Continuing Efforts

- Test blends with fluorinated component .
- Further testing of plasma and $SCCO_2$
- Clean complex hardware



Continuing Efforts

- Test compatibility with soft goods
- Round robin testing with partnering facilities
- Scale up of technologies
- Assess benefit to other government agencies and private partners