In-Space Manufacture of Storable Propellants

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NIAC PI Meeting, Seattle, 28 October 2015
SBAG, JHU, 29 June 2016
Most of the Earth-launch mass for deep-space missions is propellant – especially for return missions.

Propellant manufacture in space enables retrieval of large masses of native materials and products.

Cryogenic propellants require large masses of refrigeration/liquefaction equipment, tankage (for LH₂!) and insulation.

Storable fuels and oxidizer can be made using only water and CO₂.

Heating C-type asteroids releases abundant water and CO₂.

We are studying co-production and use of storable propellants.
Storable Propellant Production Roadmap

1. Extraction of water for use as STP propellant
2. Extraction of water and CO₂ for synthesis of storables
3. Purification of gases: elimination of sulfur and toxic gases
4. Electrolysis of water to generate H₂ and O₂ gases
5. Catalytic reaction of H₂ and CO₂ to make dimethyl ether, etc.
6. “Fuel cell” reaction of H₂ with O₂ to make H₂O₂ + energy
7. Use of DME/H₂O₂ propellant for moving large masses
What do we do where?

Full-scale storable propellant manufacture requires large energy input and complex handling.

Extraction of water alone can be done relatively simply and at lower temperatures to minimize sulfur gas production.

Water is an ideal fluid for Solar Thermal Propulsion (STP).

STP can return large masses of raw materials to Highly Eccentric Earth Orbit (HEEO): staging ground; fuel depot.

First mission extracts water for STP retrieval of large masses of raw C-type asteroid material to HEEO.
Progress on initial retrieval mission

1. Developed a mineralogical model of CI chondrites
2. Thermodynamic modeling of volatile-element release from heated asteroid mineral assemblages
3. Energy and power requirements for H$_2$O & CO$_2$ extraction
4. Development of a scheme for H$_2$O and CO$_2$ transportation
5. Showed value of STP using water vapor exhaust; showed gross inferiority of schemes seeking high I$_{sp}$ by using H$_2$ instead of water
6. Applied Tsiolkovskii’s “optimum I$_{sp}$“ theory to validate water
Decomposition Pressures of Minerals
Sulfur Dioxide Pressures, CI chondrite at 800 K

(contours of $\log_{10}$ of $SO_2$ pressure, atm)
Sulfur Dioxide Pressures, Cl at 1000 K
Storable Propellants: HEEO Operations

Experiment on extraction of volatiles from carbonaceous asteroids: strong heating to maximize volatile extraction of H, C, O, S, and N (~40% of total asteroid mass)

Develop processes for separation of volatiles and purification of water, especially sulfur removal (poisons many processes)

Refine DME and H₂O₂ production schemes and adapt them to use H₂O and CO₂ retrieved to HEEO from C asteroids

HEEO becomes the site of propellant production for use in LEO, GTO, GEO, and deep-space missions (Mars, PhD, asteroids)
Progress on Propellant Manufacture and Storage

1. Down-selected numerous schemes for H$_2$O$_2$ and DME (etc.) manufacture for co-production compatibility

2. Demonstrated ability to use only H$_2$O and CO$_2$ as starting materials for propellant manufacture

3. Developed a kinetic model for H$_2$O$_2$ storage showing decomposition rates as low as 10-5%/yr at reduced T

4. Identified and proposed solutions to problems of catalyst poisoning by sulfur gases in both fuel production and Mond processing of metals

5. Showed $I_{sp}$ of DME/H$_2$O$_2$ is 300 s; verified that each 2% of H$_2$O$_2$ dilution lowers $I_{sp}$ by only 0.6%
Condensates in the H₂O-CO₂ System
Decomposition Rate of 90% H$_2$O$_2$ in Al Tanks
Vapor Pressures of H₂O₂ Solutions