Development of Busek 0.5N Green Monopropellant Thruster

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Michael Tsay, Ph.D.
Busek, Co. Inc.
11 Tech Cir, Natick, MA 01760

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Introduction

- Monopropellant community has been pursuing non-toxic, “green” alternatives to hydrazine in the past 20 years.
- High-performance green monoprops typically consist of a fuel and a soluble oxidizer; notable oxidizers include HAN (U.S.), ADN (Sweden), HNF (Netherlands and Germany) and AN.
- Green monoprops are much favored over hydrazine in research institutions because they are non-toxic, safe to handle and pose little spill-related hazards.
- The presented work on a 0.5N AF-M315E green monoprop thruster was motivated by the need of a small, easy-to-use thruster for NanoSats and SmallSats as they grow in functionality.
- Busek is developing the 0.5N AF-M315E thruster under AF SBIR Phase II funding. The development includes an innovative, long-life catalyst and a low-power piezoelectric thruster valve.

Characteristics of AF-M315E

- AF-M315E was developed by AFRL to replace hydrazine for space propulsion applications.
- AF-M315E is benign and shock resistant, but also very energetic when fully decomposed
  - Adiabatic flame temperature ~1800^{o}C.
  - 13% increase in Isp over hydrazine.
  - 63% increase in density-Isp over hydrazine.
- Decomposition of AF-M315E is via a pre-heated catalytic reactor
  - Full decomposition leads to combustion.
  - "Quenched" reactor is characterized by partial propellant decomposition and smoky exhaust.
- Finding a suitable catalyst for AF-M315E is a challenging task due to its high flame temp
  - Ceramic-supported catalysts can easily degrade.
  - Busek is reporting a breakthrough in the catalytic reactor technology.

Quenched Reactor

Successful Ignition Following Full Decomposition

Busek 0.5N AF-M315E Thruster

- Busek's 0.5N thruster uses an innovative, patent-pending catalytic reactor
  - Monolithic design without ceramic substrate.
  - Requires no bed plates for catalyst containment.
  - Can withstand AF-M315E's harsh combustion environment; demonstrated in the stationary combustor prior to implementation.
- Reactor's pre-heat requirement was extensively studied
  - Approx. 15W is required to reach op temp.
  - <355°C, ignition failed (constant smoky exhaust, propellant dripping out).
  - 370-390°C, slow start (short pulse of smoke).
  - >395°C, reliable ignition.
- True requirement of the reactor should be less than the measured onset value (395°C) due to thermocouple's external placement.

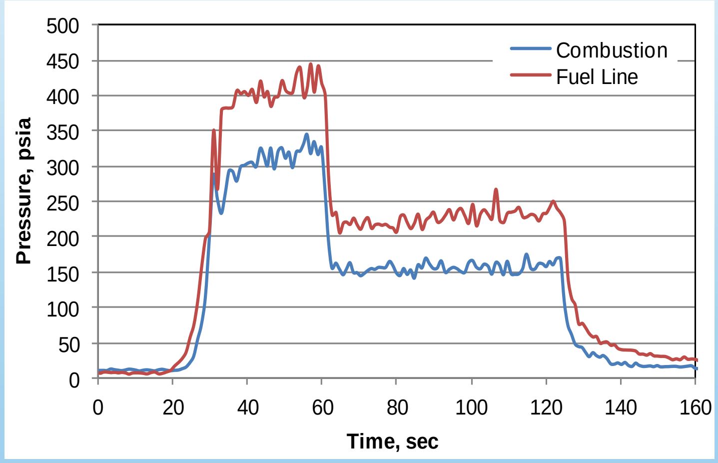
Prototype Thruster & Hot Firing

Ignition vs. Pre-Heat Temp

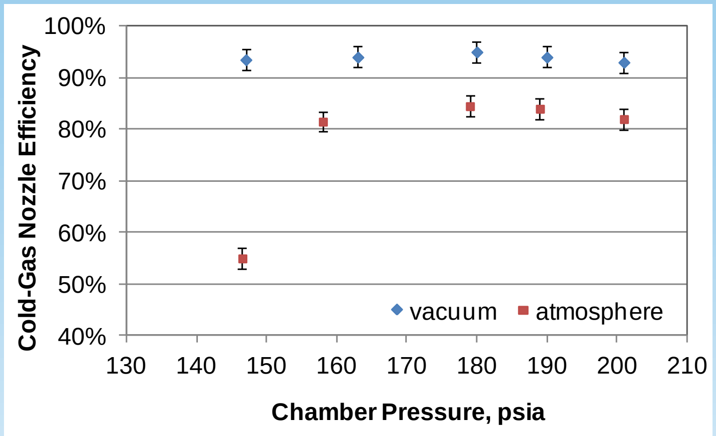
Test #	Est. Reactor Pre-heat Temp, °C	Ignition?
1	355	Fail
2	374	Slow Start
3	386	Slow Start
4	395	Onset
5	400	Success
6	424	Success

Busek 0.5N AF-M315E Thruster

- Hot-firing of 0.5N thruster was conducted with a syringe-pump feed system
  - Provides known flow rate for c* measurement and c* efficiency calculation.
  - Limited reservoir, max 60sec firing duration.
  - 20-100% propellant flow throttling is possible.
- Demonstrated 100-400psia steady-state combustion.
- Consistently obtains 89-93% c* efficiency at 200psia nominal chamber pressure.
- The thruster is equipped with a high-performance micro nozzle
  - Overcomes machining imperfection at the throat region with a post-processing technique.
  - Throat concentricity is very critical.
  - Achieves >94% nozzle efficiency in vacuum.
- 210-220sec vacuum Isp is expected.



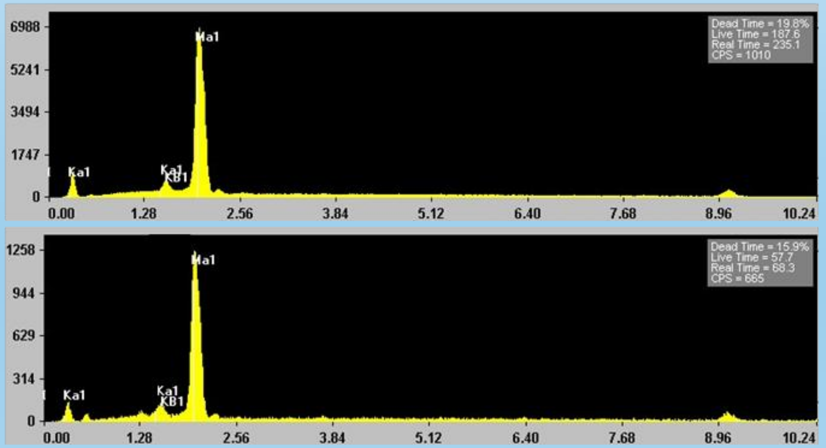
Combustion Data from Throttling Demo; 100% Flow Transitioning to 50% at 60sec-Mark



Measured Micro Nozzle Performance

Post-Test Examination of Catalytic Reactor

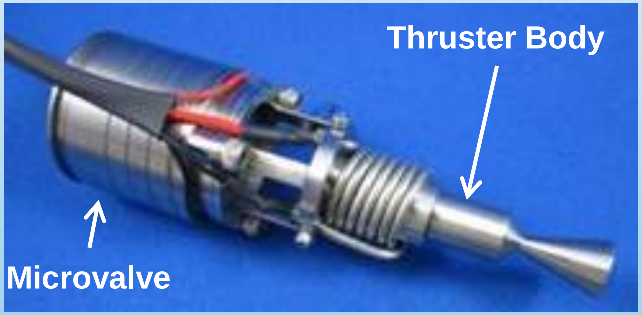
- One catalytic reactor experienced 20+ minutes of accumulated run time, during which c* performance did not decrease.
- The post-test reactor was taken out due to nozzle configuration change (a destructive procedure).
- The post-test reactor was analyzed
  - Visually it seemed intact without material or structural damage.
  - Precision scale measurement confirmed no mass loss.
  - SEM's elemental analysis showed no oxide presence; spectrum nearly identical between pre- and post-test.
- The innovative reactor design show promise of long-life without suffering from continuous performance degradation.



SEM Analysis of Elemental Spectrum for Pre-Test (Top) and Post-Test (Bottom) Reactor

Development of Piezoelectric Thruster Valve

- Busek's 0.5N AF-M315E thruster is coupled to a piezoelectric valve for propellant management.
- Busek has over 10 years of experience in developing piezo microvalves
  - Originally for EP thrusters; flight qualified hardware available.
  - Precision controllability & fast response.
  - Very low power consumption (<0.5W); attractive for small spacecraft.
  - Typically limited to low-flow applications due to very small displacement of piezoelectric actuator (tens of microns).
- Scaling up past microvalve designs for the 0.5N thruster's requirements is difficult
  - Actuator stroke vs. required flow rate.
  - High-pressure application.
  - Material compatibility.



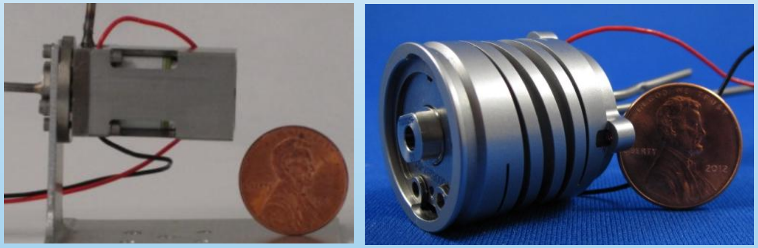
Prototype of Busek's 0.5N Thruster w/ Microvalve

Busek's Flight-Qualified Piezo Microvalve for NASA/JPL ST7-DRS Colloid Thrusters

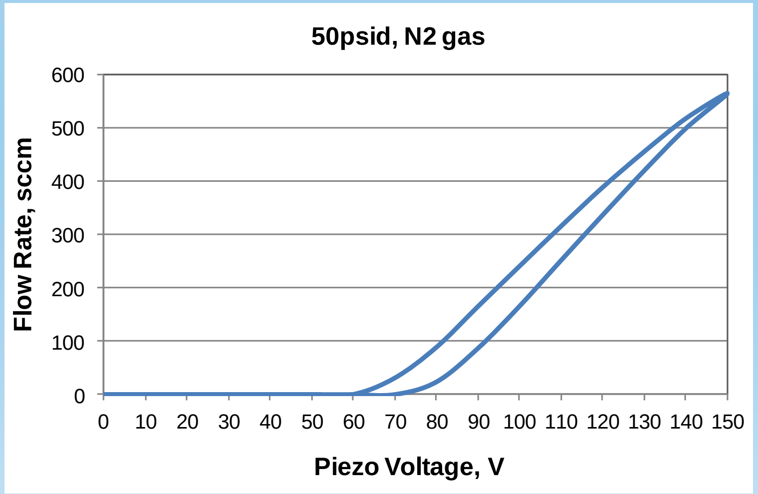
Piezo Microvalve for 0.5N AF-M315E Thruster

- With a new design approach, Busek successfully built two microvalves suitable for the 0.5N green monoprop thruster.
- Phase II valve highlights
  - Vast improvement from the Phase I valve by eliminating precision-machined parts for better manufacturability and easier assembly.
  - Reliable, repeatable & cost effective.
  - Features all-welded design w/o elastomer seal; proven up to 400psi.
  - All titanium wetted surfaces for AF-M315E compatibility; also compatible with many other gaseous and liquid propellants.
  - A true “microvalve”: small, ~0.5W power (vs. 10-15W for SOA valve) and 67g mass (vs. >100g for SOA valve).
  - Demonstrated flow curve is equivalent of 16mL/min water; target propellant flow rate is 8.5-9.5mL/min.

Busek’s Green Monoprop Microvalves



Phase I Microvalve **Phase II Microvalve**



Gaseous Flow Curve of Busek’s Phase-II Green Monopropellant Microvalve

Conclusion

- Busek's 0.5N AF-M315E green monoprop thruster in development has demonstrated great performance with consistent c* efficiency in the range of 89-93% and nozzle efficiency >94%. Vacuum Isp is expected to be 210-220sec.
- The thruster's innovative catalytic reactor has shown the ability to suppress life-limiting degradation issues that plague many other monopropellant catalysts.
- Busek's piezo microvalve complements the 0.5N thruster with its small footprint and extremely-low power draw. This system is viable for spacecraft as small as a NanoSat.
- Future work includes performance mapping, cycle test and qualification. Lifetime and propellant throughput tests will be mission-driven.
- The authors would like to thank Mr. Anthony P. Zuttarelli of AFRL/Edwards AFB for sponsoring the program.