A "Green Cold-Gas" Propulsion System for Cubesats

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Background – Cubesat Maneuvering
\- Current Cubesat maneuvering techniques are mainly passive, with little to no ability to change orbits.
\- Basic attitude control primarily using Earth’s magnetic field or gravity.
\- Very low torque, long time-constant stability (hours), and low accuracy.
\- Near-term flights with momentum wheels. Need momentum dumping.
\- Available technologies
  \- Magnets, Magneto-inertial types (solid, fluid thrusters), Gravity gradient, Drag, Electric Thrusters (ion, plasma,...)
  \- A push in research to determine a high efficiency, green propellant that is less harmful to the environment

This work is developing a "green" cold gas thruster system capable of producing thrust in the nN to mN range to be used for small satellites

Propellant Characterization
\- Experiments were conducted in a vacuum chamber that maintained a milliTorr pressure to simulate space conditions
\- Various trials were conducted to determine properties of vapor phase aqueous propylene glycol by varying:
  \- Temperature – controlled with a bang-bang thermostat
  \- Capillary tube diameter – order of hundreds of micrometers
\- Solution concentration – 0% PG (Water) up to 100% PG in intervals of 20% PG
\- Flow in the regime tested is expected to follow Hagen-Poiseuille equation

\[ \Delta P = \frac{8\mu L Q}{R^2} \]

\- Necessary data was gathered that will further the research for vapor flow through nanochannels
\- For pure propylene glycol (100%PG) flow was higher than expected considering the low vapor pressure indicating potential slip

Cold Gas Thruster and Propellant
\- Cold Gas thruster: commonly used in satellites since the 1960’s due to their relatively low complexity, efficiency, and low cost/power consumption.
\- Litan of limitations for cold gas thrusters used on cubesats:
  \- Scaling down to the pico/nanosatellite size
  \- Secondary payload status restrictions
  \- Regulations for non-toxic emissions
\- Significant benefits of using cold gas thrusters in space:
  \- Dynamic orbital maneuvers
  \- Low budget, mass, volume
  \- Minimal moving parts
  \- Relatively inexpensive fabrication costs

System Design
\- Nanochannel array separates liquid and vapor phases of propellant
\- Relays on vapor pressure of the fluid to generate thrust
\- Propellant: no pressurization and non-toxic exhaust.
\- Based on the mission criteria, a water based solution with propylene glycol was developed.
\- Propylene glycol is commonly known as modern day anti-freeze but has a multitude of applications
  \- Hygroscopic food additive
  \- Ice-fuels
  \- Pharmaceutical solvent
\- Minimizes freezing in two ways:
  \- Freezing point depression – hydrogen bond disruption minimizing chance for nucleation
  \- Less solid ice means less overall expansion at higher concentrations of PG

Propylene Glycol Freezing
\- Aqueous propylene glycol was tested in a thermally controlled chamber to measure the expansion that occurs upon transition from liquid to solid phase
\- As temperature decreases the liquid compresses slightly, but sees a dramatic increase in volume once crystallization of the water occurs (~9% for water)
\- Notably, the expansion during freezing decreased linearly with respect to increase in the concentration of propylene glycol in the aqueous solution

Thrust Generated
\- Vaporizing a propellant via nanochannels to vacuum was studied as a means of propulsion for small satellites.
\- Specific impulse (Isp) - measure of propellant efficiency

\[ Isp = \frac{m}{m_0} \frac{1}{\Delta v} \]

\[ \Delta v = \frac{v}{\sqrt{2g}} \]

\[ \text{where} \quad \Delta v = \text{velocity increment} \quad \text{and} \quad \sqrt{2g} = \text{specific gravity} \]

\- Using Aqueous PG Isp and nanochannel array dimensions the theoretical thrust was calculated
\- Thrust is tuned by adjusting the nanochannel dimensions or the propellant material properties

References

ARSKAT-1 & ARSKAT-2
\- ARKSAT-1
  \- LEO-to-Earth atmospheric composition measurements
  \- CubeSat deorbit using Solid State Inhalation Balloon
\- ARKSAT-2
  \- In space demonstration of an agile, low-cost, non-toxic, biocompatible, and non-pressurized micro-propulsion system

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