64th International Astronautical Congress 2013

Paper ID: 16580
poster
student

SPACE PROPULSION SYMPOSIUM (C4)
Electric Propulsion (4)

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ETHYLAMMONIUM NITRATE IS A SINGULAR PROPELLANT IN ELECTROSPRAY PROPULSION

Abstract

Electrostatic acceleration of charged drops to high velocities offers much greater space propulsion flexibility than conventional ion propulsion: it permits controlling the charge over mass q/m of the propellant beam, hence the specific impulse. The challenge is not in reaching relatively low q/m values, but in achieving values almost as high as offered by ion propulsion. Electrostatic atomization (electrospray) produces relatively small drops directly from the liquid bulk by generating a nanojet that breaks into charged drops of relatively uniform size. The highest q/m achievable by nanodrops is limited by the onset of ion evaporation from the drops, which leads to mixed beams of drops and ions, and lowers substantially the propulsion efficiency. Ethylammonium nitrate (EA-N) is a room temperature molten salt that has shown exceptional propulsive characteristics. Here we investigate why this is so by measuring the charge q and mass m of electrosprayed EA-N drops, from which we infer the maximum q that can be retained by a nanodrop as a function of m, qmax(m). EA-N/water solutions are electrosprayed in CO2, where evaporation of water leads to multiply charged nanodrops of pure EA-N. These are doubly analyzed in series, first according to their electrical mobility, and then by mass spectrometry. From these two measurements we determine the exact composition [(EA-N)n(EA+)z]+z of all the clusters present, including in particular the desired function qmax(m). In previous studies, using acetonotrile rather than water as the solvent, we found that qmax(m) coincided closely with the maximum permitted by the Rayleigh instability for acetonitrile drops. Water has a much larger surface tension than acetonitrile, and is used here to deliver a larger initial charge level to the nanodrops. We find that qmax(m) is now less than the Rayleigh limit for water, and is rather close to the Rayleigh limit for a substance with a ratio of surface tension over density equal to those for pure EA-N. We have extended this room temperature study to several ambient temperatures, up to T=70oC, and reached the same approximate conclusion in all cases. Unlike any other propellant previously investigated, EA-N binds charge so strongly that it does not evaporate any ions even at the maximal charging level permitted by the Rayleigh instability. The usual mechanism deteriorating the propulsive efficiency of other known propellants is therefore largely absent in the case of EA-N, explaining its singular propulsive efficiency.