ISRU OF WATER FOR INTERPLANETARY STEAM PROPULSION USING CARBON NANOPARTICLES.

Barba, N.[1], Rabade, S.[1], Garvie, L.A.J.[2], Thangavelautham, J.*[1], Space and Terresterial Robotics Exploration (SpaceTREx) Laboratory, School of Earth and Space Exploration, Arizona State University, *jekan@asu.edu, 781 E Terrace Mall, ISTB4-795, Tempe, Arizona, 85287-6004. [2]Center for Meteorite Studies, Arizona State University, 781 East Terrace Rd., AZ 85287-6004.

Introduction: There is an important need for space exploration to be sustainable, economical and routine. Nearly 95 % or more of a rocket mass launched from Earth is used for propulsion and discarded in the first few hours. The remainder contains the payload. Off-world resources can be extracted into rocket propellant and can extend the range and payload capacity of future rockets. Use of off-world resources could significantly reduce the cost of space transportation. Near Earth Objects (NEOs) and small bodies contain a range of available resources, including water ice and water as hydrates that may prove valuable.

Off-world Fuel Source: Water is a compelling choice for producing rocket propellant. However, the regolith would need to be excavated and water ice or water hydrates extracted through mechanical separation or thermal heating respectively. The extracted water could be electrolyzed using solar photovoltaics to produce hydrogen and oxygen that is combusted to provide thrust. Our work shows I_{sp} of 350 to 420 s can be achieved [1].

Challenges: However, this water could contain trace impurities including carbon monoxide and sulfur that can shorten the life of high-efficiency electrolyzers [2]. Complex processes are required to remove these impurities. All of these factors make water extraction from NEOs challenging for electrolysis.

Proposed Solution: A credible alternative is to simply extract water with impurities and heat it into steam for propulsion. Early techniques have proposed nuclear reactors for generating heat. However, launching large nuclear reactors pose logistic and transportation challenges, especially out of the Earth's atmosphere. Some techniques have proposed heating and expelling the extracted hydrogen [3]. In this work, we propose using solar concentrators and carbon-black nanoparticles to heat the water into steam. Vanta black for example can extract 99.97 % of radiation in the visible spectrum and converts it into heat. The process is very simple, efficient and contains no complex mechanisms/moving parts.

Process: The heat is first used to extract the water and condense into liquid. To produce steam for propulsion, solar thermal reflectors concentrate the heat onto the nanoparticles that heat a working fluid. The working fluid transfers this heat to the water using conduction.

Results: Our simulations shows temperatures of up to 2000 ^{o}C and I_{sp} of 190 s can be achieved with the proper design of the solar thermal reflector and heat distribution system. The steam is released through a rocket nozzle that produces thrust. This approach, while not offering superior propulsion performance compared to hydrogen-oxygen combustion is simple and robust. Steam-based propulsion is comparable to current monopropellants widely used on upper stages of interplanetary spacecrafts. It can offer higher thrust than current electrical propulsion and minimizes risk because the propellant is easy to store and is inert. We report on proof of concept laboratory studies that show carbon-nanoparticles that can convert sunlight to heat and produce steam thrust. We characterize the thrust produced and show viability of this approach using pure water, hydrated clay, and meteorites.

In-Space Demonstrator: Based on our laboratory experiments, we are developing a concept design of a 14 kg, 6U CubeSat demonstrator that would test critical technologies required for the proposed concept. The demonstrator would be launched into Low Earth Orbit or through the ISS and perform a series of experiments including demonstration of solar-thermal heating using nanoparticles, production and expelling of steam for propulsion and water extraction from regolith in space.

References: [1] Pothamsetti, R., and Thangavelautham, J, (2016) IEEE Aerospace, pp 1-10. [2] Nittler et al., (2004) Antarctic Meteorite Research, 233-253. [3] Panigua, J. et al. (2008) *STAIF 2008* 492–502.