Undergraduate Thesis Prospectus

Design of an In-Situ Fuel, Oxygen, and Potable Water Supply System on Manned Mars Missions
(technical research project in Chemical Engineering)

Manned Mars Missions: A Divisive Idea
(STS research project)

by

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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General Research Problem

How can exploration of Mars be improved?

Since the Moon landings, Mars has become one of the next major goals of manned space exploration. Six rovers have been sent to Mars since the 1970s and billions of dollars have been spent on research on robotic and manned Mars exploration initiatives (Pittman, 2011). Manned missions to Mars have been proposed for several decades ahead, some even as early as the 2020s. The minimum cost of a manned Mars mission has been estimated at $500 billion (Taylor, 2010; Weitering, 2019). Manned exploration of Mars is technically daunting. Challenges include habitation of astronauts on Mars, availability of fuel for equipment and return missions to Earth, and transportation of resources from Earth (NASA, 2015). These problems must have cost effective solutions prior to the start of the missions. Major social barriers also complicate the exploration of Mars, ranging from indifference to strong opposition. For example, only 59 % of Americans in a 2019 poll stated that "Conduct[ing] scientific research to expand knowledge of the Earth, solar system, and universe," including research on Mars, is very or extremely important to them (Associated Press, 2019). Both the technical and social problems of Mars exploration must be managed before a mission can succeed.

Design of an In-Situ Fuel, Oxygen, and Potable Water Supply System on Manned Mars Missions

How can we design a cost-effective system on Mars to produce hydrogen/oxygen fuel for transportation to and from the planet, and provide oxygen and water to the inhabitants of a manned outpost?

Our group's capstone advisor is Professor Anderson and the group members are Craig Doody, Michael Mace, Spencer Plutchak, Sabrina Stenberg, and Rahim Zaman, all of the Chemical Engineering Department. Our project goal is to optimize the utilization of Martian resources to provide water and oxygen to sustain a human colony, as well as produce enough hydrogen/oxygen fuel for their return trip to Earth. Design work for this project will be continued in the spring semester with the same team.

The National Aeronautics and Space Administration (NASA), other federal space agencies, and private companies plan to send humans to Mars in the next several decades. The costs of material and equipment transportation from Earth will comprise most of the mission costs. According to a NASA report by Kleinhenz and Paz (2017), storage costs could be drastically cut with the use of In-Situ Resource Utilization (ISRU), which will utilize Martian resources for Mars base necessities. These essentials include fuel for a return trip, as well as oxygen and water for a life support system. The process must be economically viable to ensure adequate investment, the importance of which is discussed by Shishko et al. (2015).

ISRU optimizes the use of materials, recycling where possible, as described by NASA (2019). Powell et al. explains NASA has researched optimal ways to provide oxygen and water for a Martian colony, as well as sufficient hydrogen to fuel a rocket for their return trip (2001). Hydrogen will be obtained using multiple methods and stored for later use, and the Mars Oxygen

ISRU Experiment (MOXIE) is the current method proposed to produce oxygen, as reported by Meyen et al. (2016). The water will be mined from the ground, either in solid or liquid form, and purified. Our proposal is to design a continuous process, utilizing available resources, to improve production output and energy efficiency. As seen in Figure 1, the hydrogen production will be achieved by reforming methane, collected from the regolith, and from the water-gas shift reaction. These reactions produce carbon monoxide and carbon dioxide, respectively, which can be recycled to increase hydrogen production. MOXIE will generate the oxygen necessary for the colony. Some specifications still undefined include energy sources to keep the processes running for the colony and the equipment to extract the materials from the atmosphere and regolith.

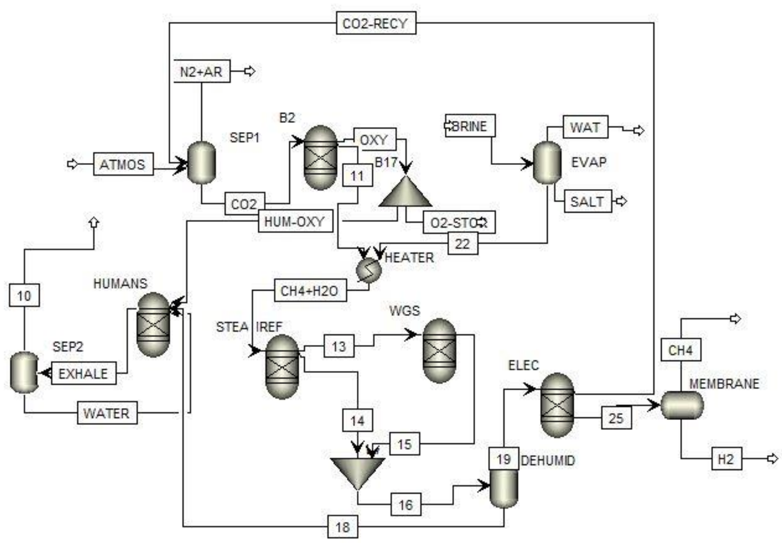

Figure 1: Process flow schematic including the integral operations of reactions, separations, and storage.

Our system consists of multiple reactor and separation units. Reactor units will reference literature for kinetic constants, catalytic behaviors, and reactor size, using hand-calculated scaling and approximation techniques when necessary. The reactions involved follow equilibrium behavior, which has several useful models to help predict properties. Separations will be evaluated using AspenTech simulation technology. Size, duty, and cost will come from

Aspen calculations, with hand calculations for initial guesses and confirmations. Aspen will also allow us to optimize energy use in the system, modelling components such as heat exchangers and turbines for energy conservation. Since we do not have means to directly test the system, the Aspen models and reactor calculations will be combined for an overall cost proposal. The costs of operation and transport of our equipment will be compared to the costs of directly transporting our products to Mars.

At the end of this project, we seek to define a process with unit operations that can produce hydrogen, oxygen, and potable water on Mars. Oxygen and water production will meet the life-support demands of 10 colonists for an indeterminate period of time, and the hydrogen and oxygen fuel will sufficiently support a return trip to Earth. Since equipment and materials will have to be transported from Earth, accurate cost estimates are integral to this project. This project will contribute to ISRU research for manned missions, and later colonies on Mars. Future research projects should include drilling designs for water extraction on the Martian surface and living spaces for the colonists.

Manned Mars Missions: A Divisive Idea

How do proponents and critics of manned Mars missions advance their agendas?

The prospect of manned Mars missions is controversial. A poll found that 37% of Americans believe that sending humans to Mars is not important and should not be done, and an additional 45% believe that it is important, but of low priority (PRC, 2018). However, an increasing number of Americans favor manned Mars missions. In the past five years, the percentage of Americans favoring manned missions has, for the first time since original data from 1969, outnumbered the opponents (McCarthy, 2019). Backing includes ideological, moral, and financial support. For example, 75% of Americans favor increasing NASA's budget by 1% for a Mars mission (Phillips & Company, 2013).

Schwartz (2011) claims humans must explore space to ensure survival of the species, due to threats such as hazardous meteor strikes, resource depletion on Earth, and overpopulation. Schwartz contends that long-term manned space exploration is growing more feasible and that space resources can be profitable. Munévar (2014) argues space exploration is necessary for long-term human survival and understanding Earth on a large scale to solve environmental problems. Entradas and Miller (2010) found that in the United Kingdom, disapproval of manned space exploration is due to insufficient knowledge of its benefits and risks, and inadequate public outreach. Launius (2003) asserts that Americans, on average, vastly overestimate NASA's budget, noting that in 1997, the average estimate of NASA's federal budget share was 20%, compared to the true value of less than 1%. He claims that such misperceptions lead many to believe that the manned space exploration budget is too large. This claim can be extended to other federal space agencies to explain opposition to Mars exploration.

NASA has proposed manned Mars missions for the value of space exploration, but has no definite plan yet. Any plan must properly allocate the investments it receives from partners to ensure that its Mars missions are successful and profitable (NASA, 2019). The nonprofit Explore Mars advocates for manned missions to Mars within the next 20 years. It testifies to Congress, hosts academic conferences, and engages in public relations (Holler, 2017). Private space industries, including SpaceX, also favor manned Mars missions, primarily for financial motives. It has received large investments for its space exploration initiatives, such as a $20 million equity venture from Founders Fund. SpaceX plans a manned Mars mission for about 2024. The managing partner of Founders Fund, Luke Nosek, claimed that he "believe[s] SpaceX will become the world leader in space transport" (Shanklin, 2008). This represents a developing shift in the U.S. from NASA toward private space industries.

The Congressional Budget Office (CBO) has faulted manned space exploration as uneconomical and hazardous. It estimates that elimination of human space programs, except for telecommunications projects, would save $73 billion between 2015 and 2023 (CBO, 2013). Many environmentalists contend that space exploration competes with more urgent sustainability needs on Earth. They prioritize global warming, pollution, and desertification over space exploration (Hanbury, 2017). This resonates with the views of 63% of Americans, who believe that monitoring key parts of the Earth's climate system should be the top priority, compared to the 18% who believe that sending astronauts to Mars is (PRC, 2018). Many oppose manned Mars missions because they believe that they will benefit only the affluent in society. They claim that only the wealthy will be able to use the technology if global catastrophe occurs and will create "a galactic upper class that rests on the backs of the earthbound" (Zimmerman, 2015). While unorganized, people with these views can diminish public support for manned Mars missions.

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