Oxygen Production on Mars with In-Situ Resource Utilization

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Space agencies and commercial companies plan to send humans to Mars as early as 2030s. However, many challenges still need to be solved before pioneering Mars. One of the challenges is the lack of oxygen (O_2), which makes up only 0.14% of the Martian atmosphere [1]. Not only is this resource necessary for breathing, but it is also needed as a propellant to launch from Mars. Over 2 years, as much as 800 tonnes of O_2 would be needed as propellant and to supply six astronauts. With the cost of sending one pound into low Earth-orbit ranging from 2,000 – 10,000 USD, shipping the required amount of O_2 to Mars would be unfeasible [2]. To address this challenge, our group has designed a process to produce 50 kg/hr of O_2 on Mars using in-situ resources, while eliminating toxic by-products.

The developed process produces O_2 from carbon dioxide (CO_2), which makes up 95% of Martian atmosphere, and recycles harmful carbon monoxide (CO) by-product into CO_2 [1]. In the first step of the process, CO_2 is separated from Martian air via cryogenic cooling. The CO_2 is then sent to an electrolyser unit, where it is electrochemically split into O_2 and CO. The CO and CO_2 mixture is sent to a membrane separator, where CO_2 is separated and recycled to the process. The remaining gas is sent to a fluidized bed reactor, where the CO is treated by reacting with the regolith (Martian soil) to form CO_2.

A preliminary economic analysis showed that equipment cost accounts for only 5% of the total project cost, with 95% of the cost being due to shipping the process to Mars. Further economic analysis was conducted using NASA's Equivalent System Mass (ESM) Analysis. This method calculates an equivalent mass due to the volume and power requirements of a system and adds these parameters with the actual mass of the equipment, therefore accounting for the infrastructure that would need to be shipped in addition to the process itself. To optimize project costs, emphasis was placed on reducing the mass, volume, and power of each piece of equipment, leading to novel designs and solutions. After optimization, the ESM of the process was 60 tonnes, which is 6.8% of the amount of O_2 that would need to be shipped to Mars, resulting in over $3 billion saved in shipping costs.

A detailed process design including equipment sizing, mass, materials, and power requirements, process flow diagram, piping and instrumentation diagrams, control strategies, and plant layout were delivered as a result of this project. Environmental impact, maintenance and safety were also analyzed for each step. An implementation plan was proposed based on mass constrains imposed by the developing interplanetary transportation technologies. Lastly, utilization of process by-products was also considered.

In summary, the developed process uses resources available on Mars to produce 50 kg/hr of oxygen, which can be used for breathing and as fuel for the return trip. In-situ O_2 production would save about $3 billion in shipping costs. Due to modular design, the O_2 production can easily be adjusted to meet growing demands. The process was optimized to minimize the mass, volume, and power requirements, resulting in a feasible ESM value. Lastly, useful by products would reduce the required shipment over time.

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