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CHEMICAL PRODUCTION ON MARS USING IN SITU PROPELLANT PRODUCTION TECHNOLOGY

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ABSTRACT

In situ propellant production (ISPP) has been examined in terms of its applicability to a manned Mars mission. Production of oxygen from Martian atmosphere was used as the baseline system for ISPP technology assessment. It was concluded that production of oxygen was an important element in a manned Mars mission which could be developed in terrestrial laboratories. Expert system methodology will be required to enable reliable, autonomous production of oxygen. Furthermore, while no major technical breakthroughs are required, this research requires a long lead time to permit its systematic evolution.

INTRODUCTION

In situ propellant production (ISPP) was described initially in 1978 (Ref. 1) as a method for producing rocket fuel for a Mars sample return mission. Use of ISPP resulted in significantly less Earth launch mass than by other concepts. The original concept proposed utilization of atmospheric carbon dioxide and absorbed water in a simple chemical processor to produce methane and oxygen. A major constraint in that study was the availability of water, but an important finding was that primitive chemical processors could be operated at very low throughputs and produce very large quantities of chemicals in time intervals of one year. Subsequently, the technology was investigated for possible applications at other planetary bodies (Ref. 2) and recently, a more comprehensive investigation of the technology required to produce oxygen from the Martian atmosphere for a low mass sample return was reported (Ref. 3). In situ production of chemicals is a logical element in an overall manned Mars program. The purpose of this brief report is to place the technological issues before the manned Mars mission working group.

The production of oxygen from Martian atmosphere is an important process both for life support and as an oxidizer source for ascent vehicle propellant. The processor technology is also an important element in a variety of other scientific and propulsive systems. Since

that technology is understood sufficiently to permit specific identification of future research needs and programmatic emphases, it will be described in some detail. The broader issue of production of fuels and other chemicals will be discussed briefly in terms of its potential for future enhancements in an overall Mars exploration program.

ISPP is an important technology in the evolution of a Manned Mars Mission because it exploits the following advantages: (1) Substitution of power generating equipment for chemical mass results in a more flexible system, (2) Radioisotope sources produce much higher energy densities (several orders of magnitude) than conventional rocket fuels when the radioisotope is used several hundred days, (3) Up to fifty percent reduction in Earth launch mass is possible by offloading the return propellant, (4) Autonomous production of oxygen at Mars is an important element in a manned Mars mission for life support, regardless of return vehicle or surface stay time, (5) ISPP can enable the return vehicle to be sent to the Martian surface well in advance of the manned landing, thereby allowing the Earth return vehicle to be certified prior to sending people to the surface, and 6) The ISPP system can be developed and tested in terrestrial laboratories.

Depending upon constraints, ISPP is an enabling technology. Furthermore, using the oxygen production technology as an example, it is possible to show that ISPP is not a radical departure from presently understood terrestrial systems. The idea of depending on the resources of an unexplored landing site for the ultimate success of a mission is both logical and consistent with historical precedent. Technological issues do remain and will be outlined subsequently.

OXYGEN PRODUCTION

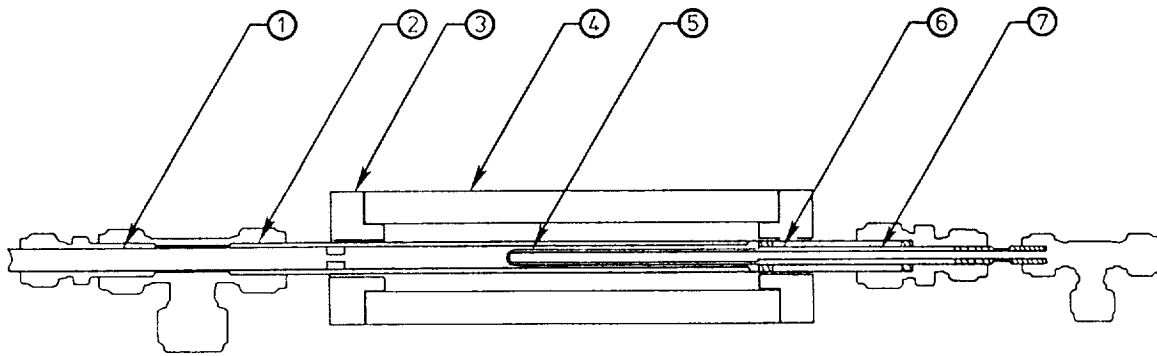
The composition of the Martian atmosphere is well documented (Ref. 4). While there may be slight variations in composition due to location and season, the availability of relatively pure carbon dioxide (95.32%) as a feedstock for oxygen production is insensitive to landing site selection. It is tempting to consider atmospheric water vapor as an equally available feedstock since the atmosphere is relatively humid (Ref. 5), but the low atmospheric pressure and temperatures never allow water vapor to represent more than a few hundredths of a percent by volume. The low density of the atmosphere (on the order of 0.02

kg/m³) means that relatively large volume flow rates of atmosphere are required to produce useful carbon dioxide flow rates, and the volume flow rates that would be required for water collection would be staggering--to say nothing of the refrigeration requirements that would be imposed for water condensation. Water in small amounts could be collected from the atmosphere for life support.

A nominal Mars environment was suggested in Ref. 3 for oxygen processor design considerations. An atmospheric temperature of 200 K, a barometric pressure of 6.8 mb, an average solar load of 140 W/m², a density of 0.018 kg/m³, and a wind speed of 1.5 m/s were assumed. Using those data, rather detailed thermomechanical designs were developed for a system that could produce 10 kg of oxygen per day. That system was assumed to have a carbon dioxide conversion efficiency of 25 percent which meant that for every mole of Martian atmosphere that passed through the oxygen processor, approximately 0.12 moles of molecular oxygen were produced.

Oxygen collection was accomplished using an electrochemical pump. Essentially, a voltage can be applied to porous platinum electrodes on both sides of a yttria stabilized zirconia membrane to selectively conduct (pump) oxygen ions across the electrolyte. By heating the collected Martian atmosphere to approximately 1270 K, sufficient carbon dioxide dissociation can occur to permit the oxygen collection to occur. That system has been studied extensively by Richter (Ref. 6), and a schematic cross section of the cell is shown in Figure 1. A schematic diagram of the oxygen processor system developed in Reference 3, is shown in Figure 2.

In order to scale up the system described for Mars sample return to manned mission size, the system mass (less electric power generator) can be scaled, to a first approximation, by multiplying the ratio of atmospheric flow rates, raised to the 2/3 power, by the baseline mass. Baseline mass is affected by trades between ascent vehicle mass and refrigeration system/electric power generator masses. However, if the baseline mass was 300 kg for a production rate of 10 kg/day with a conversion efficiency of 25 percent, a 100 kg/day system with a 20



1. INCONEL 600 TUBING 9.5mm x 0.9mm WALL
2. INCONEL 600 TUBING 12.7mm x 0.9mm WALL
3. BORON NITRIDE SLEEVE (2)
4. HEATER, LINDBERG MODEL 50012 TYPE 74-KS (2)
5. 8% YTTRIA STABILIZED ZIRCONIA TUBE WITH 0.1mm PLATINUM COAT ON BOTH SIDES 6.6mm x 1.5mm WALL
6. INCONEL 600 TUBING 9.5mm x 1.5mm WALL
7. INCONEL 600 TUBING 4.2mm x 0.1mm WALL

Figure 1. Electrolytic Cell Design

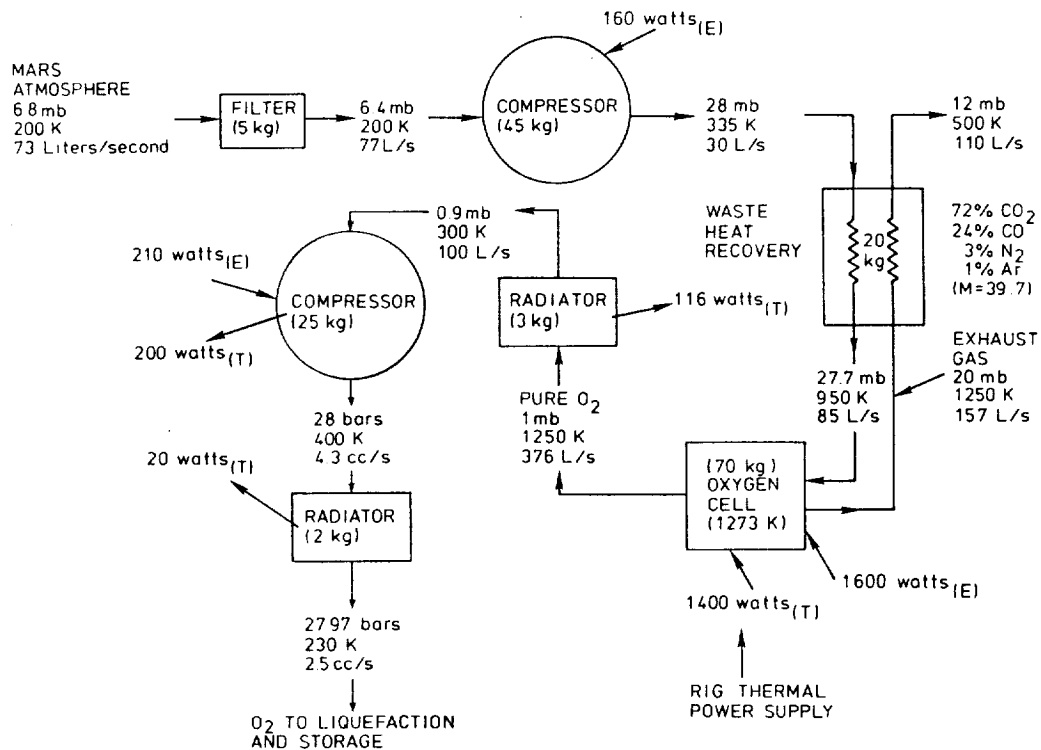


Figure 2. Schematic diagram of 10kg/day Mars oxygen production system.

percent conversion efficiency would have an estimated volume flow rate which is 12.5 times the baseline and an estimated mass of 1630 kg. The electric power requirement scales almost linearly with the throughput. Hence, if the baseline power requirement was 3000 Watts electric, the manned system would require approximately 30 kWe. That system could produce, liquefy and store 10,000 kg of oxygen in 100 days.

The technology issues identified in previous studies will be discussed briefly, and then other issues which relate to ISPP systems for production of other chemicals will be discussed.

Expert Systems

In order to minimize the possibility of a single point design failure in the system, it will be necessary for ISPP hardware to monitor itself and anticipate pending system failure. Proper design of system elements and software should enable these machines to identify pending problems and take evasive action. The nuclear and chemical industries are developing such technology at this time, but they are using massive amounts of historical data and experience to develop these systems. It will be necessary to develop sufficient long term operating histories on prototype ISPP machines to enable them to distinguish between normal degradation and pending failure.

Repair vs. Redundancy

When system elements have characteristics masses and/or volumes which are large, it is not feasible to carry duplicate or parallel elements through the system to avoid single point failures. When considered in the context of the expert system strategy, a system design that exchanges an increase in power requirements or decreased efficiency for repairability using computer controlled manipulators and common components becomes potentially a more reliable and lower total mass system. These systems are very desirable for manned missions in order to keep routine maintenance time to a minimum. Space Station experiments which are designed to develop and test autonomous/repairable chemical processor systems should be given high priority.

Mobility vs. Fixed Site

If ISPP is included on a manned mission, the efficiency and risk related to separating the processor system from the human must be addressed. It does not make sense to carry a 10,000 kg oxygen processor

system over large distances. It may make sense to move these systems for short distances in the reduced gravitational environment, to reduce the risk to manned habitat and transportation vehicles.

Filter Systems

A Mars dust filter design has been discussed in Reference 3. Based upon data returned from Mars, the dust does not appear to be a serious problem. However, filter designs which minimize inlet pressure drops and are relatively insensitive to unusual or unexpected particulate loading are needed. These systems can be designed and tested in terrestrial laboratories. The ability to remove the accumulated particulates periodically should be incorporated into the design.

Pumps and Compressors

Pumps and compressors operating at Mars will be in an operating regime which is similar to roughing pumps in vacuum facilities. Compressors will be required to elevate fluid pressures from a few millibars to a few bars. Mechanical stresses will be low, but tolerances and efficiencies of these devices will require a systematic research and development program. This program should be started early enough to permit selection of a set of generic devices which will enable the evolution of a set of common components amenable to self diagnosis and repair. The cryogenic refrigeration components will be similar.

Fault Tolerant Electrolytic Networks

The electrolytic cell system is likely to be a large matrix of cells of the type shown in Figure 1. Based on experience to date, one or more of these cells is likely to fail during an extended operation. It will be very desirable to design this system in a manner which will permit either passive tolerance of cell failures or active alteration of the flow network. This research program could greatly improve system performance and reliability.

Oxygen Distribution and Storage

It will be desirable to store oxygen and other cryogenic liquids in more than one tank. Since these liquids will likely be recycled as they vaporize due to heat exchange with the surroundings, it will be desirable to develop passive fluid management systems which use Mars gravity and density gradients to move fluids to desired locations.

Propulsion Systems

Methane/Oxygen rockets have been built and tested. However, they have not been designed for either Mars sample return or a manned mission. Those engines and a variety of other propellant and propulsion combinations should be investigated to optimize opportunities for manned exploration.

Electric Power

Power generators were not studied here, but the Galileo RTG's are sufficient for sample return. SP-100 greatly exceeds anticipated requirements for manned ISPP.

Packaging and Deployment

Depending on the power generation system selected for a manned mission, the packaging problem can be a serious problem. One advantage of ISPP is that a large, potentially hazardous power generating system can be sent in an unmanned mission in advance of the manned mission. Either way, thermal and radiation problems will require careful examination.

Radiators

While the Mars atmosphere is thin, the wind appears to blow nearly all of the time (Ref. 7). The increased energy exchange is very important for radiator surfaces with temperatures approaching Mars ambient conditions.

Trace Contaminants

A research program which identifies potential contaminants that can damage elements in the ISPP system should be undertaken. Simultaneously, realistic probabilities of contaminant existence should be developed based on current knowledge of the solar system. Study of samples collected on a precursor or early mission will be essential.

Complementary System Elements

The machinery required for in situ propellant production can be used intermittently for a variety of manned or scientific systems. This opportunity has been given little attention by the scientific community. However, the electric power and cryogenic cooling capabilities of the ISPP system can enhance many activities ranging from water collection to sophisticated chemical analyses.

Acceptance

While ISPP technology requires a different perspective for manned missions to Mars, it does not require major scientific breakthroughs. In fact, the research required to place ISPP on equal footing with other options can be accomplished at modest total costs if the program is spread over a long enough period of time. Not only does ISPP become an accepted option with increasing time, but the historical data required to develop expert system-based machinery becomes economical. However, compressing a decade of machine history into less than a year can be very expensive.

OTHER ISPP OPTIONS

I have attempted to use the oxygen production system as a base from which to identify technology issues related to in situ propellant production. It is important to realize that the simplest system is the oxygen production system, since it uses a simple chemical processor operating on an abundant raw material. If a manned station were established in the north polar region of Mars, where there is known water ice, use of water and carbon dioxide to produce methane and oxygen becomes very attractive. In addition, carbon monoxide can be recovered from the oxygen processor system and used as a fuel. Both of these systems involve more than one chemical process. The methanation process was described in Reference 1, but the extraction of carbon monoxide was not. Commercial recovery of carbon monoxide is common, but the systems require thermal energy and relatively complex flow networks (Ref. 8).

Ultimately, all manned extraterrestrial stations will likely require autonomous production of fuels and oxidizers for continued operation. Production of methane and carbon monoxide are both important resource options that should be studied in greater detail.

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