

Completed Project (2012 - 2013)

Advanced Water Purification System For In Situ Resource Utilization Project

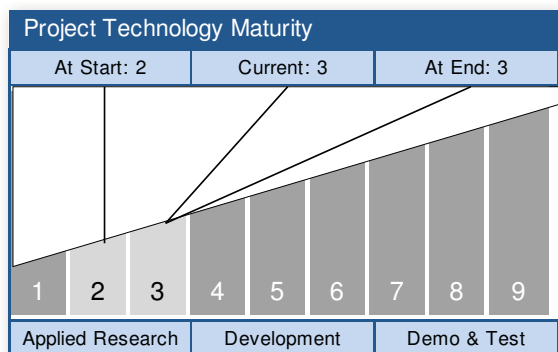
Center Innovation Fund: KSC CIF Program
Office Of The Chief Technologist (OCT)

National Aeronautics and
Space Administration



ABSTRACT

A main goal in the field of *In Situ* Resource Utilization is to develop technologies that produce oxygen from regolith to provide consumables to an extraterrestrial outpost. The processes developed reduce metal oxides in the regolith to produce water, which is then electrolyzed to produce oxygen. Hydrochloric and hydrofluoric acids are byproducts of the reduction processes, which must be removed to meet electrolysis purity standards. We previously characterized Nafion, a highly water selective polymeric proton-exchange membrane, as a filtration material to recover pure water ...**Read more on the last page.**



Technology Area: Human Health, Life Support & Habitation Systems
TA06 (Primary)
Human Exploration Destination Systems TA07
(Secondary)

ANTICIPATED BENEFITS

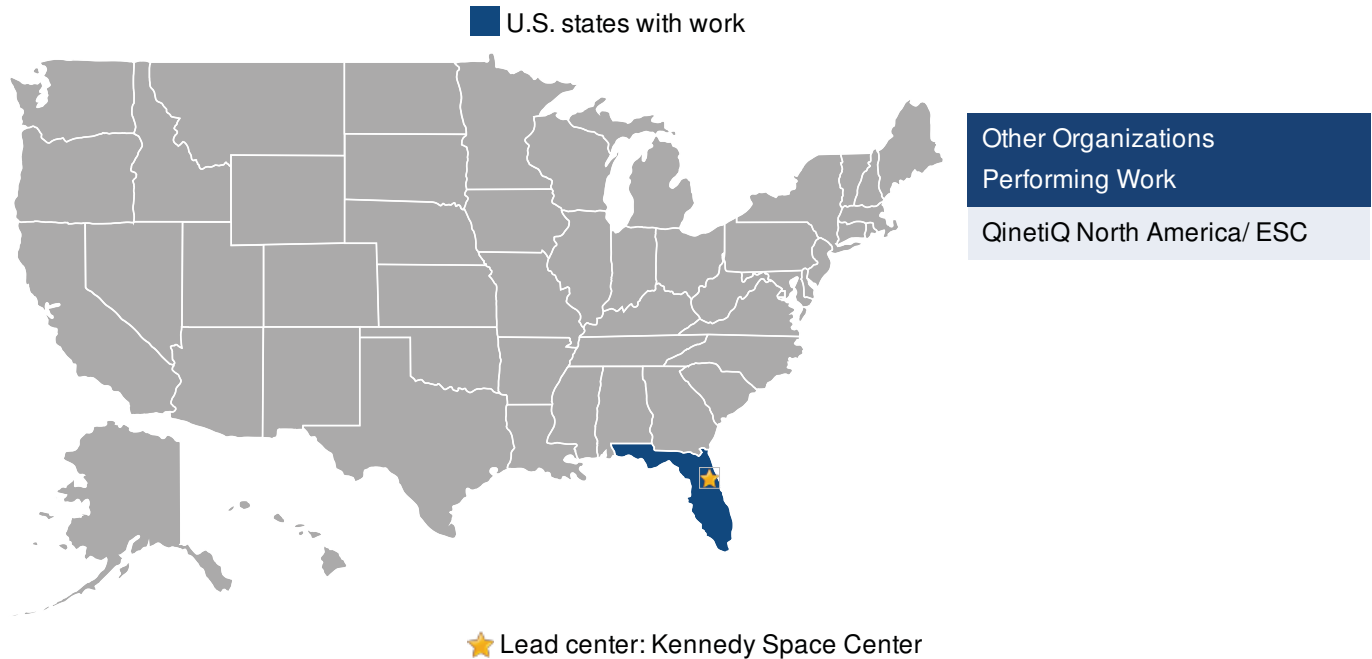
To NASA unfunded & planned missions:

The success of this technology will reduce the cost of operating and maintaining ISRU systems, enabling long-term deep-space missions.

To the commercial space industry:

Potential Customers: ISRU Environmental Control and Life Support System (ECLSS)
Space Power Systems

Read more on the last page.



DETAILED DESCRIPTION

The goal of *In Situ* Resource Utilization (ISRU) is to develop systems that allow for a long-term human presence in space without the need for replenishment of materials from Earth. Lunar regolith is of particular interest to ISRU researchers as potential source of oxygen for fuel and life support. Hydrogen, which has been detected in the permanently-shaded regions of craters near the lunar poles, can be used to reduce the metal oxides present in lunar regolith to produce water, and via electrolysis, oxygen.

Prior to electrolysis, the water generated as an intermediate product must be treated to remove absorbed hydrochloric and hydrofluoric acids, byproducts derived from trace amounts of fluoride and chloride present in lunar regolith. In terrestrial applications, removal of chloride and fluoride from water is a relatively trivial process due to the availability of consumable adsorbents, or by utilizing other processes that require frequent regeneration. None of these processes are applicable in the lunar environment, however, where resources are scarce.

We previously studied Nafion, a commercially-available sulfonated tetrafluoroethylene polymer membrane, as an ISRU filtration material because it can continuously facilitate water transport and acid rejection without ...

MANAGEMENT

Program Executive:
Burton Summerfield

Program Manager:
Nancy Zeitlin

Project Manager:
Nancy Zeitlin

Principal Investigator:
Stephen Anthony

Co-Investigator:
Scott Jolley

DETAILED DESCRIPTION (CONT'D)

the need for replacement or regeneration. While Nafion showed promise as a filtration membrane, it was unable to remove sufficient quantities of contaminants, particularly fluoride, and would require very large membrane contact areas to generate appreciable quantities of clean water. Electrodialysis was chosen as an alternative water purification process for the present study, due to its extensive industrial pedigree and demonstrated ability to rapidly produce a clean water supply and concentrated waste brine.

Electrodialysis uses the principle of ion exchange. An electrodialysis stack contains alternating cation and anion exchange membranes between two electrodes, with fluid-containing channels between each. Initially contaminated feed (diluent) and initially clean waste (concentrate) solutions are passed through every other chamber as direct current is applied across the electrodes. Anionic contaminants in the diluent solution diffuse across the anion exchange membrane toward the anode (positively charged electrode), while cationic contaminants diffuse across the cation exchange membrane toward the cathode (negatively charged electrode). The ionic species become trapped in the concentrate solution, as the current directs anions toward cation exchange membranes through which they cannot diffuse, and vice-versa.

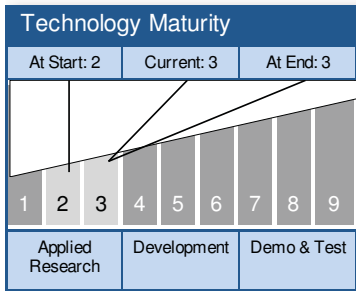
When dissolved in water, HCl and HF dissociate into their individual ionic species, i.e. H^+ , Cl^- and F^- . As a strong acid, HCl fully dissociates into its respective ions, while HF, a weak acid, only partially dissociates in an equilibrium process. It is therefore expected that HCl will rapidly and nearly completely diffuse from the diluent to the concentrate stream, while HF will diffuse into the concentrate stream more slowly, as the gradual removal of fluoride ions will allow more HF to dissociate and be removed from the diluent stream. It is also expected that as the ion concentration in the concentrate stream increases, osmotic pressure will drive water from the diluent to the concentrate stream over time, reducing the yield of clean water. As a result, experiments focused on optimizing both the quantity of chloride and fluoride ions removed from the diluent stream, and the rapidity of ion transfer.

This project has successfully demonstrated the purification of high ion content water via the use of electrodialysis. The knowledge gained during the evaluation of this process indicates that electrodialysis represents an excellent choice as a primary water purification method in long duration exploration missions to locations such as the Moon or Mars. Although this work has resulted in excellent progress towards developing a method that can be used to purify water streams produced from extraterrestrial sources, much work needs to be done to establish the best electrodialysis system for use in this environment. Further effort will need to be made to set up and evaluate an automated system that can be operated in tandem with an ISRU water generation process.



TECHNOLOGY DETAILS

Advanced Water Purification System For In Situ Resource Utilization



TECHNOLOGY DESCRIPTION

An affordable and sustainable human exploration program will require the implementation of In Situ Resource Utilization (ISRU) systems. One goal of ISRU systems is the production of oxygen and hydrogen from regolith via reduction and electrolysis reactions. Water is produced as an intermediate in this process, as are a number of undesirable contaminants, including hydrochloric and hydrofluoric acids. Typical water purification materials require continuous regeneration or replacement, and are not desirable in an environment where resources are limited.

This technology is categorized as a hardware system for other applications

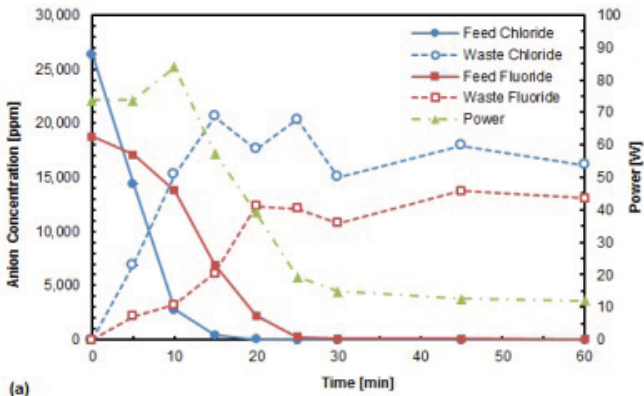
- Technology Area
 - TA06 Human Health, Life Support & Habitation Systems (Primary)
 - TA07 Human Exploration Destination Systems (Secondary)

CAPABILITIES PROVIDED

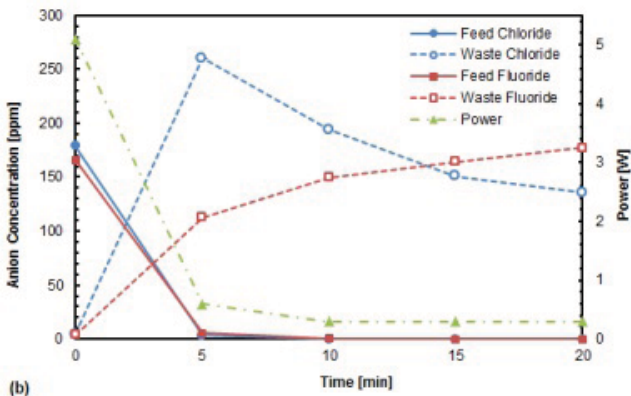
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IMAGE GALLERY



(a)



(b)

Contaminant concentration and power consumption profiles of the electro dialysis process.

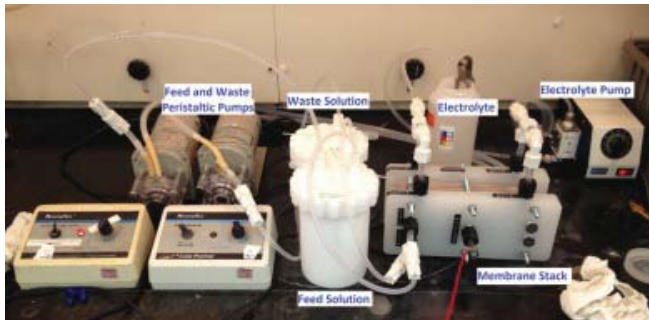
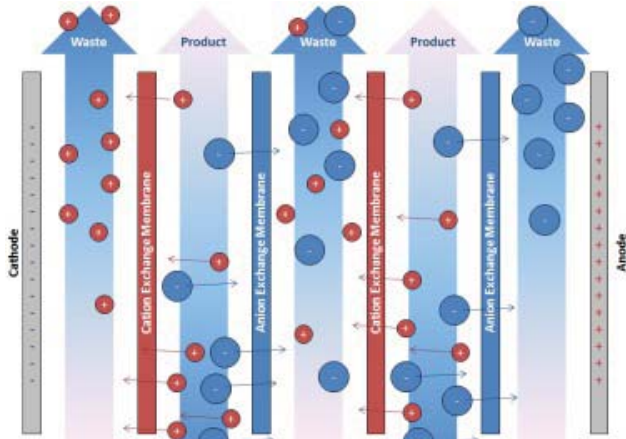


Image of the experimental apparatus used to test the chloride and fluoride removal capabilities of the electro dialysis stack



ABSTRACT (CONTINUED FROM PAGE 1)

from the contaminated solution. While the membranes successfully removed both acid contaminants, the removal efficiency of and water flow rate through the membranes were not sufficient to produce large volumes of electrolysis-grade water. In the present study, we investigated electro dialysis as a potential acid removal technique. Our studies have shown a rapid and significant reduction in chloride and fluoride concentrations in the feed solution, while generating a relatively small volume of concentrated waste water. Electro dialysis has shown significant promise as the primary separation technique in ISRU water purification processes.

