IMPLEMENTATION OF NEW SYSTEM FOR OXYGEN GENERATION AND CARBON DIOXIDE REMOVAL

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Dedication

To my wife and all of those whose efforts made this product possible, especially the committee members and those in the space industry.

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by

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DISSERTATION

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Abstract

This research effort develops an integrated system for CO_2 removal and O_2 production. A unique material, dodeca-tungsto-phosphoric acid ($H_3PO_4W_{12}O_3$; henceforth referred to as DTPA) is mixed with tetra-ethyl-ortho-silicate $Si(OC_2H_5)_4$ or TEOS. This mixture exhibits unique properties of heat absorption and high electrical conductivity. In the system described herein, the DTPA resides within a cross linked arrangement of TEOS. The DTPA furnishes a source of O_2, while the TEOS furnishes structural support for the large DTPA crystals. In addition, the large amount of H_2O within the crystal also adsorbs CO_2. It can also be cross-linked with other polymers such as polycarbonate, for different applications and properties such as flexible textiles. A set of isolated bench experiments were designed to test CO_2 adsorption, O_2 production, heat production, and voltage production were conducted to test the hypothesis that DTPA can provide CO_2 adsorption, O_2 generation, heat generation and electrical generation. Five experiments with this apparatus were conducted: (1) a mass balance experiment; (2) an X-ray diffraction experiment; (3) a photo spectroscopic experiment; (4) a calorimetric experiment; and (5) a dielectric experiment. Results illustrate that approximately 2880 grams of this material produces 576 grams of O_2, and removes 1760 grams of CO_2. The reaction also produces approximately 844 kJ/mole heat, and can supply 12.2 V potential over a period of 4.5 hours. The amount of unused material and the recycling ability suggests the usefulness of the technique to achieve between a 50-75% closed system. In addition, an experiment using ^{18}O tracer demonstrated that approximately 20% of the O_2 produced comes from processed CO_2 adsorbed by the crystal, while the remaining 80% of the O_2 produced comes from replaced O_2 within the crystal itself. The device has multiple applications including environmental control and life support for

aircraft cabins, space vehicle interiors, submarine pressure vessels, sealed armored vehicles, and personal protective equipment for individuals working in confined spaces such as mines.

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1. INTRODUCTION

1.1 Summary

This effort addresses the task of designing an integrated system for CO_2 removal and O_2 production, using a super oxide material within a capacitor chamber. The general chemical process involved in this approach can be summarized as:

1. Remove H_3PO_4 from $H_3PO_4W_{12}O_{36}$,
2. Introduce NaOH into a reaction chamber to form Na_2CO_3 and Na_3PO_4,
3. Use heat to release O_2 from WO and WO_2,
4. Regenerate $H_3PO_4W_{12}O_{36}$ from WO and WO_2 by using Na_2WO_4, H_3PO_4, HCl, and NaCl,
5. Remove waste C and Na_2CO_3 from the system.

This process can be used for enriching air with O_2, providing electrical current and heat, and removing CO_2. Using this process, a pressurized capacitor compartment could be constructed which can perform many functions needed for crew life support.

Several issues must be addressed in order to successfully meet the selected Lockheed Martin Environmental Control Life Support System validation process (Lockheed Martin Telecommunication, 2016). One system requirement shall be the need for a unit to produce at least 640 grams of O_2 per person per day (Lockheed Martin Telecommunication, 2016). A second systems requirement is that the unit removes 1760 grams of CO_2 per person per day. Thirdly, materials needed to accomplish the mission should be available as by-products of other sub systems. The amount of O_2 production and CO_2 adsorption must meet the needs of a person to perform respiration.

After a literature review of candidate oxide materials, several oxygen rich metal oxides were considered such as dodeca-tungsto-phosphoric-acid ($H_3PO_4W_{12}O_3$). The material was chosen because it contains 560 grams of O_2 per mole for one person at rest, per day. Dodeca-tungsto-phosphoric-acid ($H_3PO_4W_{12}O_{36}$) also contains one of the components needed to recharge the material, H_3PO_4.

1.2 Material Selection Process Summary

Figure 1 below illustrates a summary of the process used for dielectric material selection. The selection process for the material $H_3PO_4W_{12}O_{36}$ consisted of a survey of chemicals, both organic and inorganic that contains a high ratio of oxygen compared to the entire molecule. Such molecules include super oxides such as K_2O, Na_2O, and $H_3PO_4W_{12}O_{36}$. The molecule $H_3PO_4W_{12}O_{36}$ was chosen because it contains 22 % by weight oxygen, and was not chemically unstable, as both K_2O and Na_2O are flammable.

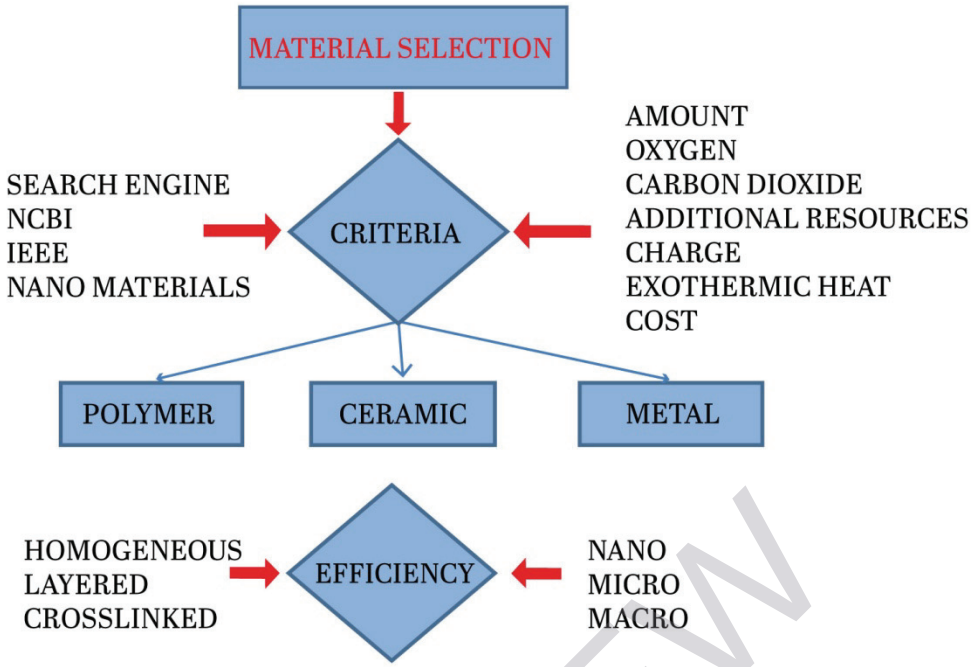

Figure 1: Decision process for material selection of dielectric, and matrix material.

An added benefit to using DTPA chemistry for O_2 production can be seen by the production of heat and electrical charge within the container system.

1.3 Description of Device

The device itself consists of an internal container with several slots intended for individual filters. These filters are actually specialized capacitors containing a dielectric that changes as a function of CO_2 content.

The device could be described as a rectangular box. Other designs include a cylindrical shape. The total volume of the device was chosen such that a suitable amount of DTPA could adsorb approximately 1760 grams of CO_2 per day per person, and produce approximately 640 grams of O_2 per day per person. (Figure 2).

Figure 2: Illustration of CooRS device.

The rectangular box contains a series of sandwiched dielectric material (DTPA and TEOS) that serves as a CO_2 adsorbent and O_2 , heat and voltage producer. The material, which lay between two conductive aluminum wafers, interacts with CO_2, H_20, and NaOH to produce carbonates (Na_2CO_3, Na_3PO_4, and WO) and O_2. Figure 2 below illustrates some geometric configurations of the device.

TOP AND SIDE SCHEMATIC VIEW OF FILTER CHAMBER

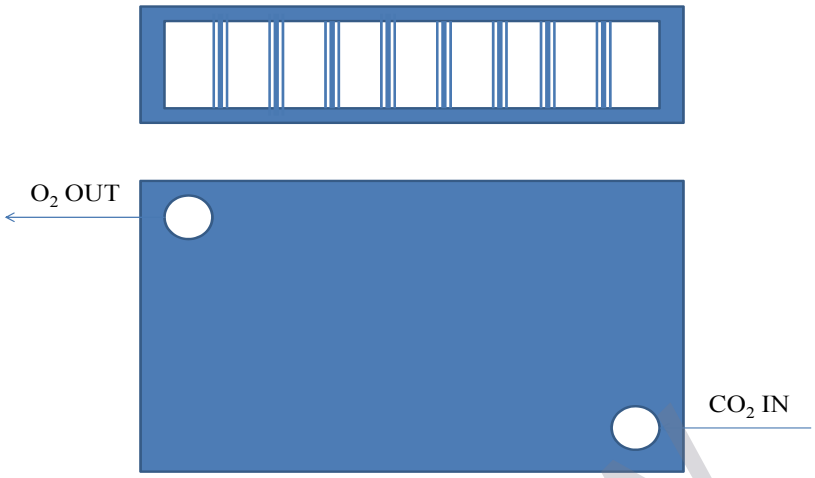

Figure 3: Schematic diagram of CO2 Removal – O2 Regeneration System (CooRS). The system consists of an outside shell housing the CO2 or air pumped through the filters, and the filter itself, which could be described as a dielectric material sandwiched between two conductive materials. This dielectric material contains CO2 adsorbing material, which generates sufficient heat in order to release O2 from O2-rich super oxides, such as H3PO4W12O36.

There are five components within the chamber of the CO_2 removal- O_2 production system, two material components within the filter system, and two chemicals within the dielectric system. The chamber itself (Figure 2) houses the filters that adsorb the CO_2 and release the O_2. Attached to this chamber are the O_2 collection tank and the CO_2 feed tank. These are seen in Figure 6a. The filters themselves (Figure 6b) contain the dielectric material itself. It could be applied to one side of the plastic grid, seen in Figure 6b. If the electrical current generated during the gas exchange process was desired, two polyaniline or aluminum wafers can be placed on both sides of the dielectric material. Two alligator leads could be connected to the grids, so that charge generated by the break- up of DTPA could collect on the surface of the wafers.

The dielectric material itself could be seen in Figures 7, 8 and 9. There are two chemical components of this system- the dodeca tungsto phosphoric acid (DTPA) and the tetra ethyl ortho

silicate (TEOS) gelatin. The arrangements of these two molecules were predicted using Ceries II and Spartan Chemical Modeling Software. The configuration represents the lowest energy state that the molecules can exist while 10-100 nm away from each other, at standard temperature (25 C) and pressure (1 atm) conditions. The material exhibits useful properties such as hydrophilicity, and stability at higher temperatures (25-80 C) as well.

A b

Figure 4: The device developed in this investigation, in which CO2 was removed and O2 regenerated in the system (Coors). The grids at the center were coated with H3PO4W12O36-Si(OC2H5)4 mixtures. Grid spacing could be varied for larger or smaller throughput of gas. Carbon dioxide enters the port at the bottom left, and O2 and N2 gas were allowed to escape at the opposite end of the unit.

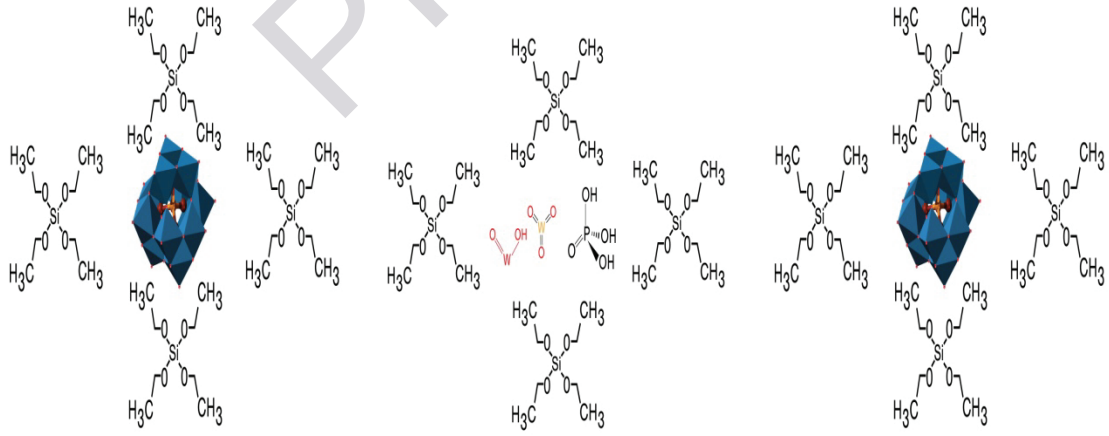

Figure 5: The structural arrangement of Si(OC2H5)4and H3PO4W12O36. The H3PO4W12O36 lies in the center while four Si(OC2H5)4 molecules, surrounding the center molecule. The configuration returns to H3PO4W12O36 upon addition of Na2WO4, NaOH, PO4, and HCl.