

Engineered Structured Sorbents for the Adsorption of Carbon Dioxide and Water Vapor from Manned Spacecraft Atmospheres: Applications and Testing 2008/2009

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ABSTRACT

Developmental efforts are seeking to improve upon the efficiency and reliability of typical packed beds of sorbent pellets by using structured sorbents and alternative bed configurations. The benefits include increased structural stability gained by eliminating clay bound zeolite pellets that tend to fluidize and erode, and better thermal control during sorption leading to increased process efficiency. Test results that demonstrate such improvements are described and presented.

INTRODUCTION

New sorbent-based systems are under development that are designed to meet the needs of future crewed spacecraft cabin Atmosphere Revitalization (AR) systems. These systems must efficiently and reliably control carbon dioxide (CO₂) and trace contaminant concentrations in the cabin atmosphere to levels necessary for long-term crewed space exploration missions beyond low earth orbit. . Sorbents such as Zeolites and Silica Gel are excellent candidates for these applications because of their high affinity for capturing molecules of interest along with their chemically inert nature and non-flammable properties. Such properties make them attractive from both

performance and safety perspectives. Their ability to be regenerated via either temperature and/or partial pressure swings facilitate their use for both closed and open loop applications, lending to their versatility and adaptability for various applications across multiple atmosphere revitalization system architectures. Historically, sorbent systems have used some form of packed bed consisting of uniformly shaped pellets or beads, as well as irregularly-shaped granular particles of sorbent media. The downfall of this type of sorbent implementation is the propensity of the material to fluidize, erode, and generate fines. Sorbent media fines have proven problematic in some aerospace applications. Developmental efforts have identified sorbent-based structured sorbents as the leading candidate to remedy this deficiency.

DEVELOPING ENGINEERED STRUCTURED SORBENTS FOR SPACE HABITATS

The use of sorbents in space applications differs from other applications because of the finite volume of the cabin atmosphere. This poses a requirement to preserve as much elemental atmospheric matter—oxygen (O), hydrogen (H), and nitrogen (N) — as possible to sustain components that are critical to a habitable cabin environment, chiefly water, breathable atmosphere, and atmospheric pressure. Military aircraft

employ structured sorbents as a design solution in systems that generate concentrated oxygen (O_2) for breathing masks (Reference 1). These systems use a sorbent monolith and operate on a Pressure Swing Adsorption (PSA) cycle. While such a process is very effective, it is not viable for CO_2 and/or trace contaminant removal on board spacecraft because it requires a slip stream of processed cabin atmosphere for regeneration. This dilutes the adsorbed byproducts with limited quantity of cabin atmosphere rendering it wasteful for dumping overboard as well as inadequate for downstream processing due to low purity. Regeneration using pressure swing is possible without employing a slip stream, but it requires a hard vacuum for the regeneration to be sufficient. Operating in space environments often yields access to such a vacuum source and such systems, referred to as Vacuum Swing Adsorption (VSA), have a history dating back to Skylab which used packed beds of sorbent beads. VSA processes are limited dumping molecules stripped from the air overboard (open loop operation) and are typically forced to operate on short half cycles due to low working capacity which causes large atmospheric gas losses.

Engineered Structured Sorbents (ESS) with metal substrates are a promising development because the metal serves to provide structural integrity as well as enabling temperature manipulation within the sorbent process. Like pressure, temperature is directly associated with the amount of sorbate (adsorbed molecules) that can be held by the sorbent. Higher temperatures result in lower sorbate retention meaning heat can be used to regenerate the sorbent by driving off the sorbate. Conversely, cooler temperatures promote adsorption. Manipulating temperature to cycle a sorbent from adsorbing to desorbing enables recovery and capture of molecules for processing and re-use. Temperature swing sorbent systems have a history of operation on the International Space Station, but the pelletized form of sorbent packed around a heater core has proven problematic while operating in micro-gravity due to generation of and the need to contain sorbent fines.

ESS DESIGN SOLUTIONS

The National Aeronautics and Space Administration (NASA) under the Exploration Life Support (ELS) project is supporting the design and test of ESS technologies to provide robust and effective Atmosphere Revitalization (AR) systems for use on lunar surfaces and beyond. Lead by the Marshall Space Flight Center (MSFC), many types of structured sorbents have been assessed. The most promising are sorbents that employ a metal substrate or core due to their durability and suitability for application to a variety of process architectures that are amenable to closed loop operations. The two primary process technologies are a Microlith[®]-based adsorption media and a thermally linked bulk desiccant. The Microlith[®] substrate is a technology pioneered by

Precision Combustion, Inc (North Haven, CT) that consists of sorbent material coated onto expanded metal meshes. The expanded metal mesh provides the dual functions of adsorbent media substrate and resistive heating element for regeneration. The thermally linked bulk desiccant is used in conjunction with a residual drier to pre-condition atmospheric gases by drying them before passing into a CO_2 or trace contaminant sorbent module. The bulk drier uses silica gel packed around a thermal carrier that transfers heat to and from the sorbent creating a nearly isothermal process. This allows for regeneration simply via a sweep of dry gas that is naturally available at the outlet of the system. Figure 1 shows a typical ESS-based AR system. As shown, the system is envisioned to consist of a bulk desiccant to remove most of the moisture upstream of the sorbent beds, then a residual drier consisting of a Microlith[®]-based adsorber followed by trace contaminant and CO_2 Microlith[®] modules. A complete continuous removal system will consist of two trains of sorbent beds, with one train adsorbing while the other train is regenerating. In this scenario, water is returned back to the cabin air for collection by the Water Recovery System, typically in a condensing heat exchanger.

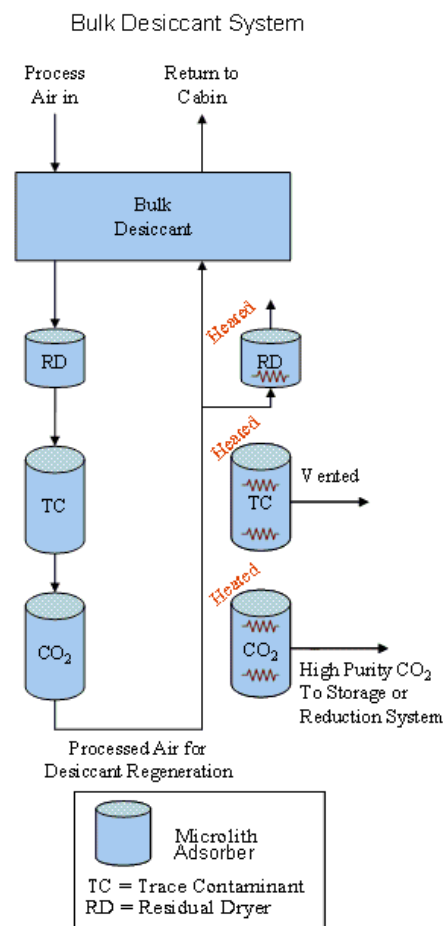


Figure 1: Microlith[®]-based Atmosphere Revitalization System for removal of Carbon Dioxide and Trace Contaminants in manned space habitats.



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TEST AND EVALUATION

To validate performance of the ESS technologies, the NASA's MSFC is conducting a series of tests in their environmental control and life support system test and evaluation facility. The following discussion describes methods, results, and future plans to characterize and further develop ESS-based processes for spacecraft cabin AR applications.

ISOTHERMAL BULK DESICCANT – The isothermal bulk desiccant uses thermal linking between adjacent adsorbing/desorbing columns combined with heat transfer with the surrounding ambient atmosphere to obtain a near isothermal process. The technique of thermal linking using porous aluminum foam as a thermal carrier in a CO₂ removal process was pioneered by United Technologies Corporation for use in an amine swing bed (Reference 2). Operating under nearly isothermal conditions aids both the adsorption and desorption process modes by mitigating process inefficiencies created by temperature spikes that result from the heat of adsorption. Regeneration is accomplished simply by flowing dry sweep gas through the water laden sorbent column. This is done simultaneously with flowing moist air through an adjacent column to provide desiccation. This concept was tested using a subscale article shown by Figure 2.

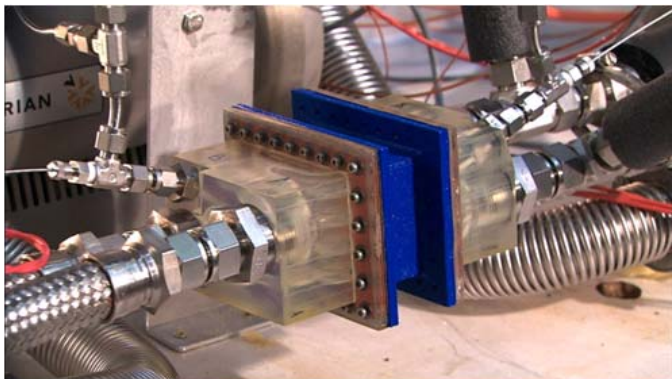


Figure 2: Subscale Isothermal Bulk Desiccant in Test Rig.

Data obtained from the subscale isothermal desiccant exhibited very promising results, yielding water removal efficiency above 90% for a multitude of operating parameters, and up to 95% at the highest tested flowrate with a 7-minute half cycle. In comparison, these cycle parameters achieved only 80% removal efficiency when operating in a typical non-isothermal bed configuration test chamber having identical proportions. Data from Figures 3 and 4 compare the performance of a standard packed bed configuration and a bed designed for isothermal operations. For this comparison, both configurations were run with a process flow of 17 liters/minute (lpm), 10 °C (50 °F) dew point, and 27 °C (80 °F) dry bulb. Figures 3a and 3b are results of the

non-isothermal bed performance in the typical packed bed configuration. The results in 3a show a steady state removal efficiency of approximately 80%, reducing the process air partial pressure from 9 torr to around 2.2 torr on average. Figure 3b shows the outlet dew point temperature at 5 minutes into the half cycle to be above -6.7 °C (20 °F), and close to -1.1 °C (30 °F) at the half cycle end.

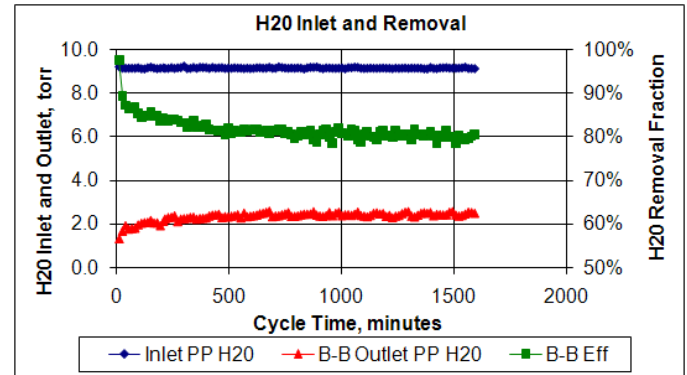


Figure 3a: Half cycle performance data points for non-isothermal gas sweep desorption process.

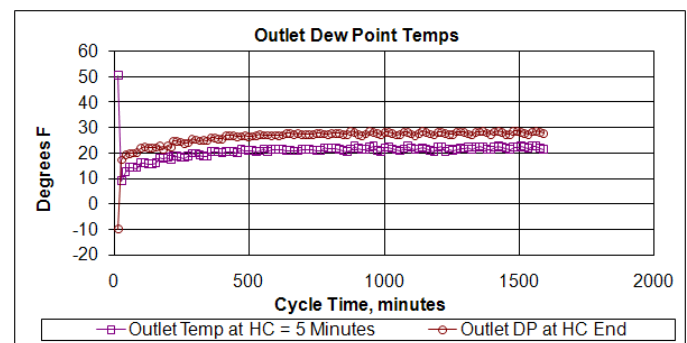


Figure 3b: Half cycle outlet dew point measurements for non-isothermal gas sweep desorption process

In comparison, the isothermal configuration revealed a marked improvement, data is provided in figures 4a and 4b. For this configuration, the steady state removal efficiency improved to near 95%, maintaining an average half cycle outlet water partial pressure below 0.6 torr, with a maximum outlet dew point of approximately -17.8 °C (0 °F)

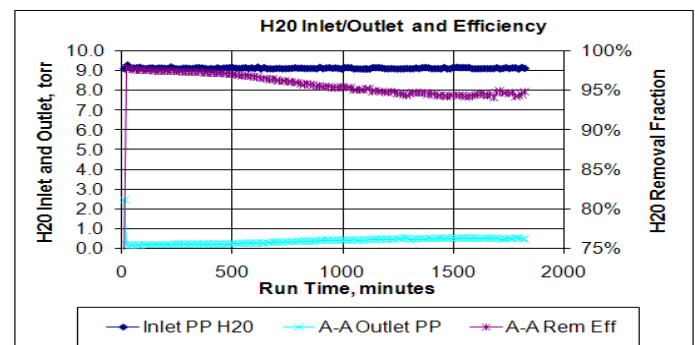


Figure 4a: Half cycle performance for isothermal gas sweep desorption.