SBIR/STTR

Small Business Innovation Research / Small Business Technology Transfer

NASA SBIR 2021 Phase I Solicitation

H3.05 Additive Manufacturing for Adsorbent Bed Fabrication

Lead Center: ARC

Participating Center(s): JSC, MSFC

Scope Title:

Additive Manufacturing for Adsorbent Bed Fabrication

Scope Description:

Current state-of-the-art (SOA) Air Revitalization System (ARS) contaminant-removal systems utilize packed beds. Packed beds have high pressure drop, large void volumes, poor heat management, and poor mechanical stability.Â Some alternate sorbent technologies (e.g., structural sorbent and monolith) have been proposed previously, but they are at a low TRL and require additional research and development to prove the concepts and resolve scale-up issues.Â Using robocasting techniques, a type of 3D paste printing, sorbent pastes are used to print sorbent beds with custom flow paths and rod size. With this approach, sorbent beds can be designed and fabricated with controlled pressure drop, tailored flow path, minimized void spaces, good heat management, high mechanical and chemical stability, and optimized structures with high mass transfer.Â In addition, having the ability to formulate oneâ€™s own sorbent paste materials allows variability in binders and co-binder selections for optimal contaminant removal and thermal performance.Â Previous studies have been completed for a variety of sorbent pastes (activated carbon [Ref. 1], zeolite 13X [Ref. 2], 5A, 4A, polymer, amine functionalized zeolite [Ref. 3], etc.). However, these works did not focus on optimizing the printed structure for cyclic operation and addressing scale-up issues.

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NASA aims to use the 3D-printed sorbent beds as drop-in replacements for packed sorbent beds such as those found in the Carbon Dioxide Removal Assembly (CDRA) on the International Space Station (ISS). Using robocasting techniques to print scale-up sorbent beds is also at a low TRLÂ and requires additional development.Â However, it is the preferred technique over other options (e.g., structured sorbents) because, if successful, the resulting technology will yield equivalent system mass reduction due to better thermal and fluid management and mass transfer properties. Technology solutions could include, but not be limited to, SOA solid sorbent materials such as zeolite 13X, zeolite 5A, silica gel, metal-organic-frameworks (MOFs), and activated carbon.Â All proposed technologies should address issues related to scale-up, paste formulation, printability, mechanical and hydrothermal stability, system design, and heaters integration. The components used in the paste formulation must abide by spacecraft chemical safety standards. This subtopic is open for novel ideas that address any of the numerous technical challenges listed below for the design and fabrication of printed sorbent beds for humidity and/or CO_2 removal.Â This subtopic does not seek new sorbent chemistries, instead, zeolite paste formulation and paste printing are desired.

- Innovative concepts on how to make silica gel paste for use in removing water from air, either in a cabin humidity control system or as part of a CO_2 removal process requiring desiccation.
- Choosing the correct paste formulation for optimal and mechanical stability.
- Designing the lattice structures to minimize pressure drop, provide large surface area for mass transfer, and prevent channeling.
- Designing a heater system for thermal regeneration of the sorbent that would minimize contact resistance between heater and sorbent and minimize mass while providing a uniform temperature throughout the bed.Â Heaters could be commercial-off-the-shelf (COTS) types (e.g. cartridge or KaptonÂ® heaters) or they could be 3D printed.

NASA is especially interested in technologies that can be incorporated into closed-loop life-support systems. Three life-support functions of particular Interest are CO_2 removal, cabin humidity control, and trace contaminant control, as solid sorbents are particularly suited to these applications.Â Technologies targeting other NASA life-support functions are also of interest.

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Proposals targeting CO_2 removal applications should consider the following:

- Improvements in sorbent CO_2 capacity and selectivity leading to smaller, more efficient components, lower energy consumption, and operation at lower CO_2 partial pressures are highly desirable.
- Increases in the robustness of sorbent materials to mechanical stressesÂ and temperature and humidity changes/cycling.
- Full-scale systems must achieve the following performance targets:
    - CO_2 removal rate of 4.16 kg/day (a 4-crew load).
    - System must Â maintain an environment with 3.0 mmHg $ppCO_2$ for cabin applications (based on the daily average $ppCO_2$).
    - System size â‰¤0.3 m^3 for a 4-crew system.
    - Average system power Â â‰¤500 W of power for a 4-crew system.
    - System mass of â‰¤450 kg for the 4-person load.
    - System must effectively separate out water vapor from cabin air (less than 100 ppm water vapor in the CO_2 product is desired).

System must effectively separate out oxygen and nitrogen from cabin air (less than 1% O_2 and 2% N_2 by volume in the CO_2 product is desired).

Expected TRL or TRL Range at completion of the Project: 1 to 3
Primary Technology Taxonomy:
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Level 2: TX 06.1 Environmental Control & Life Support Systems (ECLSS) and Habitation Systems
Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware
- Research

Desired Deliverables Description:

Phase I deliverables:Â Detailed sorbent paste formulation and analysis, proof-of-concept test data, and predicted performance (mass, volume, and thermal performance) for contaminant removal (e.g., carbon dioxide, water, or trace contaminants). Deliverables should clearly describe and predict performance over the SOA with an estimated scaled-up design for a 4-person crew.

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Phase II deliverables:Â Delivery of technologically mature components/subsystems that demonstrate functionalÂ performance with appropriate interfaces. Prototypes should be at least at a 4-crew-member scale.

State of the Art and Critical Gaps:

Current and future human exploration missions require an optimized ARS that can reduce the system mass, volume, and power, and increase reliability.Â The SOA systems (CDRA, the Carbon Dioxide Reduction Assembly (CRA), and the Trace Contaminant Control System (TCCS) are adsorbent-based or catalyst-based and their performances are limited because they use COTS sorbent materials.Â COTS sorbent pellets/beads have fixed performance parameters (e.g., mass transfer capability), which limit the ability to tailor the sorbents to meet specific needs.Â Spacecraft system design requirements differ from those used in industry.Â For example, one industrial application focuses on removing carbon dioxide at a relatively high concentration (12% from flue gas), whereas CDRA focuses on removing carbon dioxide at low partial pressure (3 mmHg). Therefore, having the ability to tailor a sorbent to NASA objectives would lead to more efficient adsorbent systems not just for the ARS but also other life support systems that utilize sorbents (e.g., the multifiltration beds).Â In addition, often times COTS sorbents are sold in bulk (impractical for NASA-scale systems) and become obsolete when manufacturers cease production.Â Instead of having to reevaluate and redesign systems for new COTS materials to address obsolescence, NASA can use a well-characterized 3D-printed sorbent formulation to remake or even to improve SOA systems.Â Here, having control over the formulation of these materials could mean continuity in the use of the materials as well and an ability to optimize and tailor the materials for spacecraft use. In addition, as new materials are available for use, (e.g., MOFs), these materials can be adapted using the same 3D-printed design. That is, once the lattice and heater designs are completed, the backbone may be used for other sorbent materials.Â Moreover, the 3D printing can be done commercially once an acceptable paste formulation has been established.Â Sorbent paste printing techniques need additional technology investment to reach a level of maturity necessary for consideration for use in a flight Environmental Control and Life Support System (ECLSS). This approach offers high returns and is a paradigm shift from the SOA, as it offers the ability to control flow paths, thermal management, and mass transfer properties.

Relevance / Science Traceability:

This technology could be a drop-in replacement for the current CO_2 adsorption beds and can be proven on the ISS with potential for application in long-duration human exploration missions, including Gateway, Lunar surface, and Mars, including surface and transit. It is imperative that CO_2 be removed to support human life during space missions. This subtopic is supported by the Advanced Exploration Systems (AES) Program in an effort to improve the SOA ARS in the ECLSS.

References:

1. WÃ³jtowicz, Marek A., Joseph E. Cosgrove, Michael A. Serio, Andrew E. Carlson, and Cinda Chullen. "Monolithic Trace-Contaminant Sorbents Fabricated from 3D-printed Polymer Precursors." (2019). https://ntrs.nasa.gov/citations/20190028890
2. Thakkar, Harshul, Stephen Eastman, Amit Hajari, Ali A. Rownaghi, James C. Knox, and Fateme Rezaei. "3D-printed zeolite monoliths for CO2 removal from enclosed environments." *ACS applied materials & interfaces* 8, no. 41 (2016): 27753-27761.
3. Lawson, Shane, Connor Griffin, Kambria Rapp, Ali A. Rownaghi, and Fateme Rezaei. "Amine-functionalized MIL-101 monoliths for CO2 removal from enclosed environments." *Energy & Fuels* 33, no. 3 (2019): 2399-2407.

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