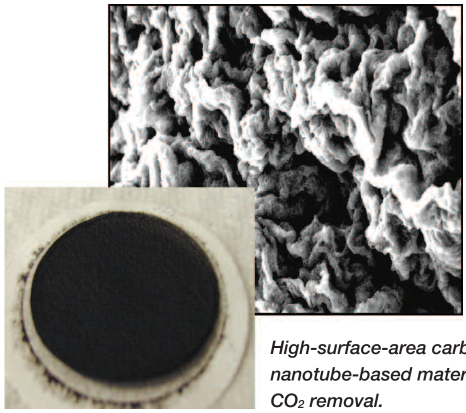
Carbon Dioxide Removal Using Carbon Nanotubes

Ram Allada, *Engineering Research Consultants, Inc.*
Padraig Moloney, *Johnson Space Center*
Pasha Nikolaev, *Engineering Research Consultants, Inc.*
Edward Sosa, *Engineering Research Consultants, Inc.*
Sivaram Arepalli, *Engineering Research Consultants, Inc.*
Leonard Yowell, *Johnson Space Center*

NASA is developing a regenerable system for the removal of atmospheric carbon dioxide (CO_2) as part of the environmental control and life support systems in the next generation of space exploration vehicles. This system would remove exhaled CO_2 from the cabin atmosphere, allowing more efficient use of oxygen supplies during extended missions. Regenerable systems for air revitalization and atmospheric maintenance will be crucial for the success of long-term missions, especially as human spaceflight extends to Mars and beyond.

In collaboration with the Johnson Space Center Crew and Thermal Systems Division, the Applied Nanotechnology Group is investigating carbon nanotubes (CNTs) as nanoscale structures with the required properties for this application, including higher surface area, enhanced porosity, and superior thermal conductivity. Although chemically inert, CNTs can be integrated with functional groups called amines, which trap CO_2. Unlike some of the materials that are presently used in spaceflight applications, these amine-functionalized CNTs would not be affected by conditions such as trace volatile organic compounds or atmospheric moisture and can, therefore, work in a number of environments and be highly selective toward CO_2. Since the material is lightweight, an adsorption system could be packaged to fit in a space suit life support system. Conceivably, the hardware could be scaled-up or downsized to accommodate various applications. Since amines allow CO_2 to be removed by low-heat (thermal swing) or simple vacuum desorption, an amine-CNT system would require significantly less power to operate in a regenerative fashion. Additional collaborations have been made with industry partners such as Hamilton Sundstrand Inc. as well as academic institutions such as Rice University and the University of Hartford.

Present research focuses on developing a solid-supported amine material based on CNTs. Collaborations with Rice University have resulted in methods for integrating amines with CNTs by directly attaching amine molecules to the sidewalls of the nanotubes. Using chemical functionalization methods helps to increase the stability of the material since it reduces the likelihood of evaporation of the amine chemical during vacuum or thermal swing regeneration processes. Thermal stability becomes a key driver for Mars life support since those systems will require thermal swing regeneration. Recent investigations of nanotube functionalization show that single-wall carbon nanotubes can be integrated with amines, and that the chemical treatment results in a high degree of functionalization. By developing an analytical technique that combines x-ray photoelectron spectroscopy with thermogravimetric analysis, the group was successful in determining the thermal stability of materials and understanding when various phases of material degradation occur. Experimental work also shows that the amine remains completely bonded to the nanotubes at temperatures well above those used to regenerate the amines. Thus, the chemical bonding of the amine to the support phase allows the adsorbent to be thermally robust, and also allows for the potential of thermal regeneration of the material over a multiyear mission.



High-surface-area carbon nanotube-based materials for CO_2 removal.

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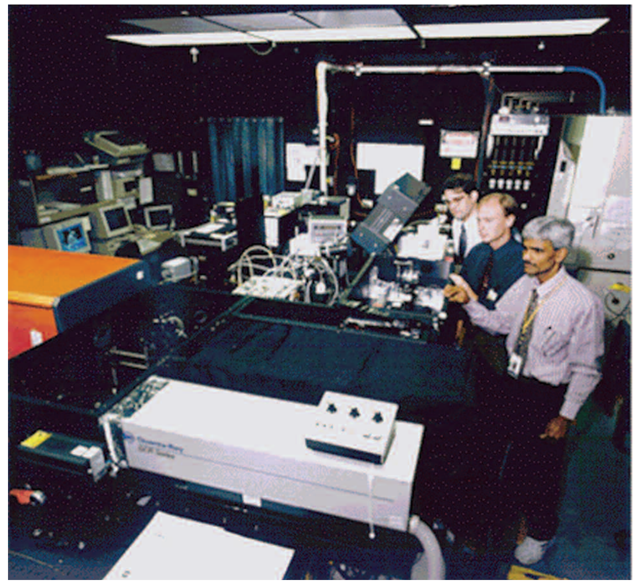
continued

High-resolution imaging techniques are used to characterize the physical morphology of the media that result from the configuration of the nanotubes. These tortuous networks of nanotubes possess unique surface area characteristics, which can allow higher accessible surface area for bonding with amines. This insight into the morphology of the adsorbent is correlated with the CO_2 adsorption capacity. Initial measurements of CO_2 uptake capacities of the first-generation CNT-amine materials show capacities that are on par with the state of the art. The present efforts center on optimizing the performance by investigating a variety of amines including complex polymers and ethanolamines, which have been well characterized by the energy and specialty chemicals industry for large-scale gas-scrubbing applications. Subsequent work extends to develop materials that can also remove trace contaminants from the atmosphere using the same adsorbent system.



Laser production facility at Johnson Space Center showing open oven and laser beam optics.

The team's industry partners will provide crucial guidance, talent, and capabilities for developing a prototype system that can be evaluated in real-use systems, while the Crew and Thermal Systems Division is evaluating and guiding the development process by sharing its insight on how these systems perform in space. These partnerships promote the development of novel life support systems from the materials chemistry standpoint as well as systems-level engineering and integration. Eventually, this technology will reach all areas of space environmental control and life support, including the next generations of spacecraft, space habitats, and beyond.

The technology for regenerable low-power CO_2 removal is also beneficial to a number of terrestrial applications. As the proposed research has direct significance toward environmental control for enclosed systems, it could be employed by the submarine community, which requires systems that maintain air quality in sealed environments, and possibly for portable breathing systems. More importantly, regenerable technologies for CO_2 removal will have a tremendous positive impact on the environment, especially for pollution control in the energy industry and general management strategies for greenhouse gases in the atmosphere.