Nanomaterials for Advanced Life Support in Space systems

Rama kumar Allada, Ph.D.
NASA Johnson Space Center
Houston, TX
Ram.allada-1@nasa.gov
• Introduction
  - Nanomaterials research at NASA JSC
  - Focus on carbon nanotubes

• Research and accomplishments in CO₂ removal
  - Current Technology
  - Goals
  - Results

• Research and accomplishments in water purification
  - Current Technology
  - Goals
  - Results

• Next Steps
Nanomaterials: Fundamentals to Applications

**Growth/Production**
Laser and HiPco Production and Diagnostics

**Characterization**
Purity, Dispersion, Consistency, Type SWCNT Load Transfer Single Fiber Diffusivity

**Processing**
Purification Functionalization Dispersion Alignment

**Collaboration**
Academia, Industry, Government

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### Applications For Human Spaceflight

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<th>APPLICATION</th>
<th>PARTNERS</th>
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<td>Ultracapacitors</td>
<td>EP, Glenn, Industry</td>
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<td>Proton Exchange Membrane – PEM - Fuel Cells</td>
<td>EP, Glenn, Industry</td>
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<td>RCRS - Regenerable CO₂ Removal System</td>
<td>EC, Ames, Industry</td>
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<td>Active / Passive Thermal Management Materials</td>
<td>EC, Rice, ORNL, Industry</td>
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<td>Nanofiltration for Water Recovery</td>
<td>EC, Industry</td>
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<td>Electromagnetic Shielding Materials (ESD/EMI)</td>
<td>EV, Rice, LaRC, Industry</td>
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<td>NX, Rice, PV, LaRC, Ames</td>
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<td>Nanotube-Based Structural Composites</td>
<td>ES, Rice, UH, LaRC</td>
<td>X X</td>
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Nanomaterials: Single Wall Carbon Nanotubes

Unique Properties
- Exceptional strength
- Interesting electrical properties (metallic, semi-conducting, semi-metal)
- High thermal conductivity
- Large aspect ratios
- Large surface areas

Possible Applications
- High-strength, light-weight fibers and composites
- Nano-electronics, sensors, and field emission displays
- Radiation shielding and monitoring
- Fuel cells, energy storage, capacitors
- Biotechnology
- Advanced life support materials
- Electromagnetic shielding and electrostatic discharge materials
- Multifunctional materials
- Thermal management materials

Current Limitations
- High cost for bulk production
- Inability to produce high quality, pure, type specific SWCNTs
- Variations in material from batch to batch
- Growth mechanisms not thoroughly understood
- Characterization tools, techniques and protocols not well developed
Air Revitalization using Carbon Nanotubes

- CNTs have useful properties that make them suitable for use in regenerable adsorbent technologies
  - High surface area and porosity – more adsorbent in less volume
  - Thermal conductivity – useful for thermal regeneration of packed beds
  - Chemical inertness along with potential functionality – the support phase can be bonded to scrubbing polymers such as amines
Initial Results and Technology Assessment

2004 Results

• Carbon Nanotubes have high surface area: bucky pearls, fibers, bucky paper

• TGA experiment: the amine is reactive with the CO$_2$ gas stream

• Poor adherence to nanotube surface - requires a specific pore size and shape

• We need a better way to integrate the support phase with the amine
Functionalization of SWCNTs with Amines

• Since amines are volatile the coating would be prone to degradation during repeated thermal or vacuum driven renewal of the adsorbent.

• Chemically bonding of the amine to the support phase was a solution to this problem.
Experimental conditions

- Flow rate 500 cc/min - 1% CO₂ (balance N₂)
- Regeneration: Low vacuum (off-line) for 1 hour
Results: Functionalization

FTIR and Raman spectroscopy data provide evidence of surface modification of the SWCNT, which indicates that carboxylic acid groups are bonded to the carbon nanotubes.
Results: Thermal Decomposition and XPS

XPS analysis of the nitrogen peak serves to monitor removal of amines (nitrogen) as a function of temperature via changes in peak height. Comparison of TGA curves for functionalized and coated SWCNT indicates that the amine remains attached to SWCNT well above the TSA temperature range.
Results: Comparison with current technologies

- High equilibrium capacity
- Lower regeneration capacity - poor vacuum results in incomplete desorption
Next Steps

- Investigate derivatizing SWCNTs with NASA approved amine formulation
- Testing and determining CO2 uptake capacity; both maximum and cyclic
  - Thermal swing
  - Vacuum swing
- Plans for scale-up
- Integration into flight hardware
Nanostructured Water Disinfection Device

- Efficient disinfection
- Low power
- No consumables

Collaboration between Crew & Thermal Systems and Structural Engineering Divisions of NASA JSC.

Nanostructured Water Flow

C60

UV Source

- Water Flow

Nanostructured Water Disinfection Device
Ultra Violet Test Stand

Bring all those pieces together and ......
Fullerene Coated slides

• Fullerene can be dissolved from a bulk material (colloids) into single fullerene particles (Bucky balls) with certain solvents.
  – Toluene
  – Carbon Disulfide
  – Benzene

• Slide preparation
  – Etched
  – Hydrofluoric (HF) Acid
  – Etched and HF
  – Surface Application
Singlet oxygen generation

UV FFA Concentration Analysis
(CS₂, HF-Scratched)
Year 1 results: Bacterial efficacy

- No Microbial Control
- UV
- UV + Fullerene

Graph showing CFU/ml vs Time (min): 0, 50, 100, 150, 200, 250, 300.
Next Steps

• Investigating substrate preparation methods by vapor deposition

• Testing
  – bacterial degradation
  – coating longevity

• Scale-up to bench top device
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