Science of Advanced Materials on the Space Shuttle & the International Space Station – Spin off applications on Earth

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Experiments in Space

Advanced Materials
- zeolites

Biomaterials, Plant growth

Human Life Sciences

Combustion
Why Grow Advanced Material Crystals in Space?

SCIENTIFIC RATIONAL
- Eliminate sedimentation
- Diffusion limited growth
- Secondary nucleation effects minimized

Overall effect: crystals with fewer defects

Economic Rational (Zeolites)
- Chemical Process Industry’s major catalytic material,
- Wide range of applications,
- Exotic use
ZEOLITE- MOLECULAR SIEVE

Zeolites (more than 50 types)
Alumino silicate crystals

$M_{2/n}\text{-}-\text{Al}_2\text{O}_3\text{-}x\text{SiO}_2\text{-}y\text{H}_2\text{O}$

Nanoporous crystal structure.

Some areas of use:
- Economic and social impact
- Cat. cracking in petroleum refineries (gasoline production)
- Ion exchangers (water treatment, powdered detergents)
- Gas or liquid separation processes, petrochem. catalysts
- Nanocomposites, antibacterials, hosts for microencapsulation.

Worldwide market over 2.5 billion USD
Categories of Crystals Growth in Space

- **SOLUTION**
  - Proteins (Drug Design)
  - Zeolites (petrochemicals, Fuel cells, Antibacterial agents)
- **VAPOR Phase**
  - Mercury Cadmium Telluride $\text{Hg}_1-x\text{Cd}_x\text{Te}$
  - Electronics
- **From MELTS**
  - Gallium Arsenide GaAs (selenium doped)
  - Mercury Zinc Telluride $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$
  - Cadmium Zinc Telluride $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$
  - Electronics
Where Were These Experiments Held?
Columbia Space Shuttle STS-73
USML-2 (United States Microgravity Lab-2)
International Space Station - US Lab

EXPRESS Rack

EXpedite PRocessing Experiments on Space Station
Experiments Are Transported to ISS

MPLM at Kennedy Space Center (KSC, Florida - 2002)

MPLM is being transported to ISS

MPLM = Multi Purpose Logistics Module
Facilities

“Expedite the Processing of Experiments to Space Station Rack” (EXPRESS Rack)

FACILITY OBJECTIVE
Provides simple, standard interfaces to accommodate drawer-level, locker, and modular-type payloads. The EXPRESS Rack concept provides the capability for a simple and shortened integration cycle.

FLIGHT OPERATIONS SUMMARY
Transported in MPLM to Orbit with partial subrack payload complement
Rack transferred to Destiny and installation checkout performed
“Zeolite Crystal Growth Furnace” (ZCG)

Al Sacco, Ph.D.; Nurcan Bac, Ph.D. Center for Advanced Microgravity Materials Processing (CAMMP), Boston

RESEARCH OBJECTIVE

• Use the ISS Microgravity environment to grow larger crystals with improved defect structure for zeolites, or other materials to enhance their adsorption properties and catalytic performance in important chemical processes, electronic device manufacture, and other applications

FLIGHT OPERATIONS SUMMARY

• ZCG is mostly autonomous except crew interaction required for:
  Start up
  Shutdown
  Sample change out (experiment runs last 10-20 days)
  Monitoring: Photography and check temperatures at predetermined intervals
  Packaging samples for return to Earth
“Dynamically Controlled Protein Crystal Growth” (DCPCG-V/C)

Lawrence DeLucas, Ph.D.; University of Alabama, Birmingham

RESEARCH OBJECTIVE

• Develop an automated crystallization system that provides real-time control of the supersaturation levels and assess the usefulness of dynamic control for improving the success of space-based protein crystal growth experiments

• DCPCG-V uses nitrogen gas to influence the rate of evaporation of the protein solution to induce crystal growth

• Compare microgravity vs. 1-g results in crystal quality, growth rates, movement and distribution, and vapor diffusion equilibration

Pictured above is the Commercial Vapor Diffusion Apparatus inside the CRIM.
ZCG (Zeolite Crystal Growth) FURNACE ON THE SPACE SHUTTLE – Al Sacco Jr. and N. Bac

Specs
- Power (heat-up) : 150 - 200 W
- Power (steady state) : 90 - 170 W
- Weight (loaded) : ~ 75 kg
- Temperature : 88 - 190 °C
- Samples : 38 autoclaves

ZCG Furnace was lost when Columbia (STS-107) Shuttle burned as it entered the atmosphere 1/2/2003
Space Development - Zeolite X

- USML-2
- USML-1
- Commercial
Single Crystal X-Ray - Zeolite A

SPACE

TERRESTRIAL
Transmission Electron Microscope (TEM)
Zeolite Beta- Defect-Free Crystal

Ground

Space
PROTEIN CRYSTAL GROWTH

Commercial Protein Crystal Growth.
Space grown crystals become Benchmarks.
Structures are better defined

**Impact:**
DESIGN OF NEW ANTIVIRAL DRUGS

Courtesy of Prof. Larry Delucas, UAB The Center for Biophysical Sciences and Engineering (CBSE)

(a) Space  (b) Terrestrial
CONCLUSION – Space Results

- Large and structurally defect-free zeolites and proteins are grown in space.

These become benchmark crystals.

- AFM results indicate smooth surface for space grown zeolite crystals with distinct growth planes.

- Knowledge base from space grown products enable us to synthesize them better on earth.
ASTRONAUTS AND COSMONAUTS TRAINED ON THE ZCG EXPERIMENT

Bonnie Dunbar - STS-50 (1992)
Vladimir Dezhurov - ISS Inc. 3 (2000)
Yuri Oniferenko - ISS Inc. 4 (2001)
Carl Walz - ISS Inc. 4 (2001)
Peggy Whitson - ISS Inc. 5 (2001)
Ken Bowersox - ISS Inc. 6 (2002)

STS – Space Shuttle Columbia flight crew
ISS – International Space Station Crew
Inc = Increment # on orbit

Kalpana Chawla (The late) - STS 107 Columbia
Laurel Clark (The Late) - STS 107 Columbia
Applications - Zeolites in Medicine

- Known biological properties
- Long term stability
- Ability to reversibly bind to small molecules
- Size and shape selectivity
- Low cost

Silver Ion, Ag⁺

- Antibacterial effect known since the ancient times
- Strong antibacterial activity
- High stability
- Very broad spectrum
- Exerts its effect through binding to bacterial DNA and inhibiting the most important metabolic activities of the cell such as transport processes and respiration.
- Metallic silver has only slight antibacterial effect when compared to Ag⁺.

PU-Zeolite Nanocomposites

- Powder form of zeolites limit their use especially in manufacturing field.
- Zeolites can be incorporated into medical grade polyurethanes (PU)
- Antibacterial effect of Ag\(^+\)-zeolites may contribute to the efficacy of PU in biomedical applications.

Results – Microbiology

• Antibacterial effect of composites

a: Ciprofloxacin
b: PU
c: PU-cAgBeta
d: PU-AgX
e: PU-AgA

**Application of Zeolites in PEM Fuel Cells**

**Reactions:**

**PEMFC**

Anode: $H^2 \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2}O_2 + 2e^- + 2H^+ \rightarrow H_2O$

$\frac{1}{2}O_2 + H_2 \rightarrow H_2O$

**DMFC**

Anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode: $\frac{3}{2}O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

$CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O$
Polymer Electrolyte Fuel Cells (PEMFC) Applications-Anode, Polymer Electrolyte, Cathode

Limitations with current perfluorosulfonic acid membranes (Nafion):
- Loss of conductivity when dehydrated
- Low operating temp. (80°C)
- High cost

Motivation for Elevated Temperature (100°C-200°C) PEM Fuel Cell Operation:
- Enhanced kinetic rates
- Lower CO poisoning
- Improved water and thermal management
- Alleviate system integration issues

Requirement of New Polymer Electrolyte Membrane for High Performance PEMFC
- Cheap, high Tg temperature and long durability
- High proton conductivity at elevated temperature and lower relative humidity

P. Costamagna, S. Srinivasan, J. Power Sources, 102 (2001) 242
Effect of inorganic additives on proton conductivity

SUMMARY
Knowledge base from space grown advanced materials (zeolites and protein) results in spin-offs for new products for the society. Some of these are:
Antibacterial Zeolites -
New Antiviral drug design (Proteins)
Nanocomposite zeolite-polymer fuel cell membranes. Portable power, or utilization of hydrogen energy in the future
Microencapsulation of fragrance in zeolites for extended release in detergents/softeners
Thank you for the opportunity

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