Advanced Exploration Systems
Logistics Reduction and Repurposing
Trash-to-Gas & Heat Melt Compactor

KSC

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NASA, NE-L  NASA, NE-M  QinetiQ
Advanced Exploration Systems
Logistics Reduction and Repurposing
Trash-to-Gas

Task Lead: Dr. Paul Hintze, NE-L
KSC Team: Anne Caraccio, NE-L; Steve Anthony, NE-F; Tony Muscatello, NE-S; Jim Captain, ESC; Bobby Devor, ESC; Doug Tomlin, NE-L; Lashelle McCoy, ESC; John Bayliss, NE-L; Katie Zadjel, GP-L;
1. Project Structure
2. “Trash to Gas”
   — Anne Caraccio, NE-L
3. “Smashing Trash! The Heat Melt Compactor”
   — Andrew Lane, NE-M
4. “Heat Melt Compaction as an Effective Treatment for Eliminating Microorganisms from Solid Waste”
   — Mary Hummerick, QinetiQ North America
5. Questions
LRR Project Structure

Advanced Exploration Systems

Logistics Reduction and Repurposing (LRR) (JSC)

Trash to Gas (KSC)

Heat Melt Compactor (ARC)

Logistics to Living (JSC)

Advanced Clothing System (JSC)
Trash to Gas Project Structure

Trash to Gas

- Steam Reformer (GRC-SBIR)
- Gasification (KSC)
- Ozone Oxidation (ARC)
- Pyrolysis (ARC SBIR)
- Low Temp Catalytic Decomposition (GRC)
- Incineration (KSC)
Trash to Gas Project Structure

Trash to Gas

Steam Reformer (GRC-SBIR)

Ozone Oxidation (ARC)

Low Temp Catalytic Decomposition (GRC)

Gasification (KSC)

Pyrolysis (ARC SBIR)

Incineration (KSC)
Why?
Mass & Volume
Where Does the Trash Go?
Waste Processing Objectives

- Propellant (methane)
- Environmental control and life support system gas (water and oxygen)
- ISRU/Utilizing resources wisely
- Volume reduction
- Resitojets

\[
\text{TRASH} \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{Ash} \\
\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}
\]
Waste produced by a crew of 4 on a 360 day exploration mission (by mass), ~2500kg/yr

From Mike Ewert Data @ JSC LRR Logistics Model
Waste Simulants

Low Fidelity
- Polyethylene

Medium Fidelity
- Low Fidelity listed materials
- MAGs, (diapers with sodium polyacrylate)
- Combinations of Nylon, PET, Polyamide, Al
- Cotton towels

High Fidelity
- Medium Fidelity listed materials
- Simulated human wastes
- Simulated food wastes
Waste Simulants

Low Fidelity
- Polyethylene

Medium Fidelity
- Low Fidelity listed materials
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- Cotton towels

High Fidelity
- Medium Fidelity listed materials
- Simulated human wastes
- Simulated food wastes
Trash $\rightarrow$ CO$_2$

CO$_2$ + 4H$_2$ $\rightarrow$ CH$_4$ + 2H$_2$O
First Generation Reactor Lab Set Up
First Generation Reactor
Second Generation Reactor
Test Matrix

— Goal:
  • Maximize CO2
  • Minimize: Reaction time, consumables and power

— Variables
  1. Inlet Flow Rate
     — 1-5 SLM
  2. Inlet Gas Composition
     — N₂, N₂/Air, Air
  3. Reactor Temperature
     — 1 °C/min, 10 °C/min, 50 °C/min
  4. Waste Simulant
     — Low / Medium / High Fidelity
Test Matrix

— Favored Test Conditions

1. Inlet Flow Rate
   — 5 SLM

2. Inlet Gas Composition
   — Air

3. Reactor Temperature
   — Quickest Ramp to 500 - 600 °C

4. Waste Simulant
   — High Fidelity
Products

TRASH $\rightarrow$ $H_2O + CO_2 + Al + Ash + Tars

- **Major Products**
  - $CO_2$

- **Minor Products**
  - $CO$, $CH_4$, $H_2O$, $C_2H_4$, tar, and ash
Trash Conversion

1st Generation Reactor

- Converted trash: 28.11%
- Recovered mass: 63.65%
- Recovered water: 8.23%

2nd Generation Reactor

- Converted trash: 35.41%
- Recovered mass: 58.45%
- Recovered water: 6.14%
2nd Generation Reactor with Air:
5 SLPM and ~100g of trash

Average of Testing

- CO2 Yield
- CO Yield
- CH4 Yield
- Recovered Ash and Al
- Recovered Condensables

Mass, grams
## Water Analysis

### Total Organic Carbon Analysis

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total Organic Carbon, (ppmC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap Water</td>
<td>2.2</td>
</tr>
<tr>
<td>2nd Gen Reactor</td>
<td>33399</td>
</tr>
<tr>
<td>2nd Gen Reactor with cyclone filter, granular activated carbon, heated tubes</td>
<td>3949</td>
</tr>
<tr>
<td>2nd Gen Reactor with cyclone filter, granular activated carbon, heated tubes, <strong>Dolomag catalyst</strong></td>
<td>2698</td>
</tr>
</tbody>
</table>

_Microincinerator determined not flammable._

_Elemental Analysis Results to come...._
Production

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>AIR FEED (SLM)</th>
<th>1st Generation Reactor (≈10g trash)</th>
<th>2nd Generation Reactor (≈100g trash)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/yr</td>
<td>kg/yr</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>5</td>
<td>128.49</td>
<td>393.09</td>
</tr>
<tr>
<td>CO</td>
<td>5</td>
<td>15.59</td>
<td>26.83</td>
</tr>
<tr>
<td>THEORETICAL CH₄</td>
<td>5</td>
<td>46.75</td>
<td>143.03</td>
</tr>
</tbody>
</table>

According to NASA’s Exploration Systems Architecture Study estimates, approximately 4,000 kg per year of O₂/CH₄ (mixture ratio of 3.6:1 by mass) propellant is needed for an ascent stage of a Lunar Exploration Mission.

**Possible Theoretical Production**
- 800 – 1500 kg of methane/year
- At current size not enough for this specific lunar ascent vehicle of LOX/CH₄ propellant
Conclusions

- Thermal degradation of trash reduces volume while creating water, carbon dioxide and ash.
- CO₂ can be fed to Sabatier reactor for CH₄ production to fuel LOX/LCH₄ ascent vehicle.
- Optimal performance: HFWS, full temperature ramp to 500-600°C
- Tar challenges exist
- Catalysis: Dolomag did eliminate allene byproducts from the product stream.
- 2nd Gen Reactor Studies
  - Targeting power, mass, time efficiency
  - Gas separation,
  - Catalysis to reduce tar formation
  - Microgravity effects
- Downselect in August will determine where we should spend time optimizing the technology
Smashing Trash!

The Heat Melt Compactor.

Andrew Layne, NE-M2
HMC Project Goals

- The project shall develop a prototype Heat Melt Compactor (HMC) for ground based experimentation that will:
  - Demonstrate the feasibility of compacting trash (10:1) into a sterile puck that can be used for radiation shielding.
  - Demonstrate the feasibility of compacting trash within the constraints of the ISS/express Rack environment
    - Power
    - Heat rejection
    - Acoustic limits
    - Human Factors
    - Safety – Toxicity/off-gassing/ flammability
    - ISS Express Rack volume (double middeck locker equivalent)

Note: Future Deep Space Habitats have a high likelihood of being volume and resource constrained as well.
HMC Generation 1.
2008 Final assembly and first testing
2009 Testing – volume reduction, water reduction, shuttle waste samples
2010 Converted to vertical orientation. Testing with brine. Technical design review.
2012 More microbio analysis runs. Minicell foam testing.

HMC Generation 2.
Solids contaminant control, Gas contaminant control, Water recovery, Control and Data acquisition system, Cooling.
HMC Mechanical Systems Overview (2)

HMC SYSTEM SECTION VIEWS
Ram Design - Requirements

• Ram Requirements
  – Compacting trash
    • Max. Pressure: 182 psia (Based on blocked vapor pressure)
  – Heating trash
    • Max. Temperature: 375 F
  – Sealing compaction chamber and fluid recovery system from actuator mechanism.
    • Hydraulic piston-style pressure Seal (air and water effective)
  – Non-adhesion to trash products (food, molten plastic)
    • Scraper
    • Non-stick surface treatment
Ram Design
Overall Geometry

Front (trash) Side

Back (actuator) Side

Ram Assembly weight: 20.71 lbs
Ram Design – Materials

• **Materials**

  • Ram Face-plate
    
    17-4 PH Stainless Steel – good strength and corrosion resistance. (Alum and Titanium strength down at temp.)
  
  • Ram Skirt/Seal Retainer
    
    Stainless Steel compatible with face-plate and appropriate stiffness for supporting seals.
  
  • Bearing Plates
    
    Titanium – Weight reduction, compatible with actuator adapter.
  
  • Seals (Custom machined by Parker Hannifin Corporation)
    
    - Scraper: PEEK
    - Wear-ring: PTFE
    - Pressure-seal: PTFE
  
  • Heaters:  Custom Silicone pad-heaters (OEM Heater)
  
  • Sensors:  RTDs supplied by OEM Heater
Ram Design – Operational Components

- Pressure Seal
- Wear Ring
- Scraper
- Electrical Terminal blocks
- Actuator adapter
- NEDOX coating on ram face
- Heaters
Ram Design - Analysis

• Structural Analysis
  - Stress plot shown of von Mises Stress given 182 psi pressure load applied to ram surface and restrained at bearing plate and chamber walls.
  - Stainless steel modulus of elasticity used (28,012.6 ksi)
  - Analysis indicates stresses are below allowable.

<table>
<thead>
<tr>
<th>Material Properties Ph17-4 H1025 Plate (4 in thick or less)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Yield Str-LT</td>
</tr>
<tr>
<td>Ultimate Str-LT</td>
</tr>
</tbody>
</table>
Parts & Assembly
Heat Melt Compaction as an Effective Treatment for Eliminating Microorganisms from Solid Waste

Mary P. Hummerick, Richard F. Strayer, Lashelle E. McCoy and Jeffrey T. Richards
Engineering Services Contract, Team QNA, Kennedy Space Center
Anna Maria Ruby and Ray Wheeler
NASA, Kennedy Space Center, FL 32899
John Fisher
NASA, Ames Research Center, CA
One of the technologies being tested at NASA Ames Research Center (ARC) for the Advance Exploration Systems program and as part of the logistics and repurposing project is heat melt compaction (HMC) of solid waste.

- Reduces volume, removes water and renders a biologically stable and safe product.
- The HMC compacts and reduces the trash volume as much as 90% greater than the current manual compaction used by the crew.
Generated Wastes

- Approximately 1633 gm per crew member per day, 30-45% of that total being water.
- Many of the solid waste components are readily biodegradable organic materials such as food and human solid waste supporting the growth of microorganisms including potential human pathogens.
- Microbial metabolic by-products can also be generated causing unpleasant odors and accumulation of volatile organic compounds (VOCs).
Objectives

The project has three primary objectives.

1. Microbiological analysis of HMC hardware surfaces before and after operation. Are there "cross-contamination issues"?

2. Microbiological and physical characterization of heat melt tiles made from trash at different processing times and temperatures.

3. Long term storage and stability of HMC trash tiles or "Do the bugs grow back?"
Objectives 2 and 3. Preparation of Inoculated Trash

- To perform studies on the survival of microorganisms in waste treated by HMC, waste was:
  - Prepared
  - Sterilized (ETO)
  - Inoculated with a known density of microorganisms that if survive, could be recovered and enumerated. Un-inoculated controls were included.
Inoculum Development

- Three microorganisms were tested for use as an appropriate inoculum.
  - *Bacillus amyloliquifaciens* a spore forming bacteria that has been recovered from shuttle trash,
  - *Rhodotorula mucilagenosa*, a yeast also recovered from shuttle trash
  - *Micrococcus luteus*, a gram positive bacteria commonly found in the environment.

- Bags of “sterilized” trash were inoculated in duplicate with 15 ml of each culture density \((10^9, 10^8, 10^7)\) in 1 ml amounts into 15 different food items in the simulated/ersatz trash.
Inoculum recovery

Colony counts (cfu/g of wet trash) from trash samples. Actual recovery is after 24 hr incubation at room temperature.

<table>
<thead>
<tr>
<th>Inoculum</th>
<th>B. amyloliquefaciens</th>
<th>M. luteus</th>
<th>R. mucilaginosa</th>
<th>B. amyloliquefaciens</th>
<th>M. luteus</th>
<th>R. mucilaginosa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E+09</td>
<td>2.20E+06</td>
<td>4.00E+05</td>
<td>3.00E+05</td>
<td>5.30E+06</td>
<td>3.22E+05</td>
<td>9.65E+05</td>
</tr>
<tr>
<td>1.00E+08</td>
<td>3.60E+05</td>
<td>6.60E+05</td>
<td>1.20E+05</td>
<td>1.91E+06</td>
<td>&lt;1.61E+04</td>
<td>1.21E+05</td>
</tr>
<tr>
<td>1.00E+07</td>
<td>7.80E+04</td>
<td>3.00E+05</td>
<td>2.00E+05</td>
<td>3.00E+05</td>
<td>&lt;1.69E+04</td>
<td>5.57E+04</td>
</tr>
</tbody>
</table>

- *M. luteus* was below detection from simulated trash samples inoculated with the two lower cell concentrations. *B. amyloliquefaciens* is known to produce bacteriocins and *M. luteus* is sensitive to these antimicrobial compounds. For this reason we eliminated *M. luteus* from the inoculum mixture.

- The calculated recovery estimate assumes no growth during the 24 hr incubation period. Actual counts show an increase in bacterial and yeast numbers after 24 hours incubation at room temperature. Growth of bacteria and yeast during shipping can, thus, be expected.
Objective 1.
Hardware Surface Samples Results

• Varying degrees of microbial growth were found depending on the surface sampled.
  – Generally, the piston surfaces exhibited much lower microbial counts than the groove surface.

• Most of the bacterial species isolated are spore forming Bacillus species resistant to heat.

• Two of the organisms recovered from the surfaces of the compactor, *Bacillus amyloliquefaciens* and *Rhodotorula mucilaginosa* are the organisms used to inoculate the trash for the long term storage studies.
<table>
<thead>
<tr>
<th>Tile #</th>
<th>Surface</th>
<th>Bacteria</th>
<th>Fungi</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 DL</td>
<td>Comp. Piston</td>
<td>Bacillus amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rear Piston</td>
<td>Bacillus subtilis subtilis ATCC=6051</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Groove</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. subtilis subtilis ATCC=6051</td>
<td>R. mucilagenosa&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phyllosticta maydis</td>
</tr>
<tr>
<td>11 DL</td>
<td>Rear Piston</td>
<td>S. capitis capitis ATCC=27840</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. epidermidis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. lugdunensis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. subtilis subtilis ATCC=6051</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strep. Salivarius</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Groove</td>
<td>B. subtilis subtilis ATCC=6051</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bacillus atropheus&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>12 DL</td>
<td>Wall</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rear Piston</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>13 DL</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>7M</td>
<td>Comp. Piston</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Wall</td>
<td>Bacillus pumilus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rear Piston</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. pumilus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. atropheus&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Groove</td>
<td>Curtobacterium flaccum faciens</td>
<td></td>
</tr>
<tr>
<td>8M</td>
<td>Comp. Piston</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Wall</td>
<td>B. amylo liquefaciens&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Organism used for inoculation. <sup>b</sup>BI test strip organism
Objectives 2 and 3. Tile Processing and Sampling

- BI test strips (NAMSA, Northwood, Ohio) were incorporated into the trash before compaction to test the efficacy of the HMC process in the reduction or elimination of microorganisms.

Figure 1. HMC tile showing excised spore strips (arrows).

Figure 2. Picture A shows sample procedure using hand press with ½ inch hole punch (B) resulting in a core sample (C).
Objective 2.

Process Parameters

- Simulated, trash was used as the HMC feed to produce the tiles for this study.
- Process parameters (time and temperature) used in these experiments were 130°C for 2 hours, 140°C for 2 and 3 hours and 180°C for 2 hours as determined and processed by ARC investigators.
## Process Time and Temperature Studies

Results of microbial analyses and some physical parameters for core samples cut from HMC product tiles treated at different time and temperature regimes (130°C or 140°C)

<table>
<thead>
<tr>
<th>HMC tile number</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>7m</th>
<th>8m</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMC process temperature</td>
<td>130°C</td>
<td>140°C</td>
<td>140°C</td>
<td>130°C</td>
<td>140°C</td>
<td>140°C</td>
</tr>
<tr>
<td>HMC process duration</td>
<td>2 hrs</td>
<td>2 hrs</td>
<td>3 hrs</td>
<td>2 hrs</td>
<td>2 hrs</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Weight loss (%)</td>
<td>24</td>
<td>25</td>
<td>19</td>
<td>16</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Core sample growth</td>
<td>4/10</td>
<td>1/10</td>
<td>6/10</td>
<td>3/10</td>
<td>3/10</td>
<td>5/10</td>
</tr>
<tr>
<td>G. stearothermophilus +</td>
<td>3/3</td>
<td>0/2</td>
<td>0</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>B. atrophaeus +</td>
<td>4/4</td>
<td>3/4</td>
<td>0</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sterilization time (hrs)</td>
<td>.49</td>
<td>.54</td>
<td>1.5</td>
<td>.54</td>
<td>.52</td>
<td>.52</td>
</tr>
</tbody>
</table>

- Weight loss possibly indicating a loss of water, was inconsistent with temperature treatments.
- Both sets of BI test strips from tile 10 grew after treatment and core samples showed the most diverse growth with the isolation and identification of 9 different species. This tile was subjected to the lowest temperature and shortest sterilization time.
**Process Time and Temperature Studies – Microbiology Results**

<table>
<thead>
<tr>
<th>Tile 10</th>
<th>Tile 11</th>
<th>Tile 12</th>
<th>Tile 13</th>
<th>Tile 7m</th>
<th>Tile 8m</th>
</tr>
</thead>
<tbody>
<tr>
<td>130°C</td>
<td>140°C</td>
<td>140°C</td>
<td>130°C</td>
<td>140°C</td>
<td>140°C</td>
</tr>
<tr>
<td>2 hrs</td>
<td>2 hrs</td>
<td>3 hrs</td>
<td>2 hrs</td>
<td>2 hrs</td>
<td>2 hrs</td>
</tr>
</tbody>
</table>

- **Bacteria and fungi isolated and identified from tile core samples cut from HMC product tiles treated at different time and temperature regimes (130° C or 140° C)**

<table>
<thead>
<tr>
<th>Tile 10</th>
<th>Tile 11</th>
<th>Tile 12</th>
<th>Tile 13</th>
<th>Tile 7m</th>
<th>Tile 8m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brevibacillus agri</td>
<td>Neisseria flavescens</td>
<td>Brachybacterium rhamnosum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. subtilis subtilis</td>
<td>Penicillium chrysogenum,</td>
<td>Streptococcus oralis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus pasteuri</td>
<td>Epicoccum nigrum</td>
<td>Streptococcus mitis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kocuria kristinae</td>
<td></td>
<td>Streptococcus salivarius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. epidermidis</td>
<td></td>
<td>Bacillus oleronius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streptococcus salivarius</td>
<td></td>
<td>Moraxella osloensis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bipolaris micropus</td>
<td></td>
<td>Penicillium chrysogenum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaetomium atrobrunneum</td>
<td></td>
<td>Sphingomonas sanguinis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Objective 3.
Long Term Storage Studies

- HMC processing time and temperature used for the tiles prepared for this study was 180°C for 2 hours and 40 minutes.
- Four time points or storage durations, 0, 45, 63 and 65 days at ISS like storage conditions (25°C, 50% RH and 3500 ppm CO₂,) were tested for the recovery of the bacterial/yeast inoculant, CO₂, and O₂.
- It was decided to include a study using a longer duration (3.5 hours) at 150°C.
Long Term Storage

Results of microbial analyses and some physical parameters for core samples cut from HMC product tiles (180°C, 2hrs, 40 mins).

<table>
<thead>
<tr>
<th>Storage duration (days) and tile number</th>
<th>Uninoc. Control, T=0 (1m)</th>
<th>Inoc. T=0 (3 m)</th>
<th>Inoc. T=45 (4 m)</th>
<th>Inoc. T=63 (5 m)</th>
<th>Inoc. T=65 (6 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss (%)</td>
<td>23</td>
<td>25</td>
<td>30</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>Core samples showing growth</td>
<td>7/10</td>
<td>10/10</td>
<td>3/10</td>
<td>4/10</td>
<td>5/10</td>
</tr>
<tr>
<td>R. mucilaginosa recovery</td>
<td>Not inoculated</td>
<td>NEG</td>
<td>NEG</td>
<td>POS</td>
<td>NEG</td>
</tr>
<tr>
<td>B. amyloliquifaciens recovery</td>
<td>Not inoculated</td>
<td>NEG</td>
<td>NEG</td>
<td>POS</td>
<td>NEG</td>
</tr>
</tbody>
</table>

- Data from tiles 3m-6m indicate incomplete sterilization and survival of bacteria and fungi up to 65 days.

- In processing these tiles, the actual sterilization time (time in which the interior of the tile reached sterilization temperatures) varied.
Long Term Storage Microbiology Results

Bacteria and fungi isolated and identified from tile core samples cut from HMC product tiles stored for different periods. (180 C, 2hrs, 40 mins).

<table>
<thead>
<tr>
<th>Uninoc. Control, T=0 (1m)</th>
<th>Inoc. T=0 (3m)</th>
<th>Inoc.T=45 (4m)</th>
<th>Inoc. T=63 (5 m)</th>
<th>Inoc. T=65 (6m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No IDs</td>
<td>Bacillus soli</td>
<td>B.thuringiensis</td>
<td>B. amyloliquificiens*</td>
<td>Strep. Salivarius</td>
</tr>
<tr>
<td></td>
<td>B. thuringiensis</td>
<td>Strep. mitis</td>
<td>Strep. mitis</td>
<td>Bacillus mojavensis</td>
</tr>
<tr>
<td></td>
<td>B. alkalitelluris</td>
<td>Cladosporium</td>
<td>Strep. salivarius</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P. agaridevorans</td>
<td>cladosporoides</td>
<td>Veillonella dispar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B. megaterium</td>
<td>Penicillium</td>
<td>Strep. Parasanguinii</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B. niacini</td>
<td>chrysogenum</td>
<td>Neisseria flavescens</td>
<td></td>
</tr>
</tbody>
</table>

*Organisms used for inoculation.

Tile 5, which was in storage for 63 days is the only tile in which we were able to recover the inoculants, B. amyloliquificiens and R. mucilaginosa.
<table>
<thead>
<tr>
<th>Treatment and disk number</th>
<th>13M</th>
<th>14M</th>
<th>15M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss (%)</td>
<td>12%</td>
<td>22%</td>
<td>13%</td>
</tr>
<tr>
<td>Core samples showing growth</td>
<td>0/0</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>B. atrophaeus spore strips (Top)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>G. stearothermophilis spore strips (Top)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>B. atrophaeus spore strips (Bottom)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>G. stearothermophilis spore strips (Bottom)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>B. atrophaeus spore strips (Middle)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>G. stearothermophilis spore strips (Middle)</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>R. mucilaginosa recovery</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
<tr>
<td>B. amylovorans recovery</td>
<td>neg</td>
<td>neg</td>
<td>neg</td>
</tr>
</tbody>
</table>
Gas Sampling and Analysis of HMC Tiles

Storage bags used to store HMC prepared tiles. Picture A shows the bags inside the chamber. B shows samples being taken for gas analysis.

No biological activity as indicated by an increase in CO₂ could be detected.
A number of VOCs were detected even after 200 days of storage.
Conclusions

• The process of heat melt compaction of ersatz solid waste was tested for its ability to sterilize the waste and render a biologically stable tile.

• Our analysis showed that organisms inoculated into the waste, *B. amyloliquefaciens* and *R. mucilaginosa* could not be detected in all but one tile after compaction at 180°C.

• Treatment at 150°C for 3.5 hours achieved sterility as determined by our testing.

• Finding viable organisms in the core samples of the HMC produced tiles seems contradictory to the negative growth results from the BI spore strips.
  - Heating and exposure to sterilization temperatures in the interior of the tile may be inconsistent so sterilization may not be achieved through the entire tile. Results from tile 5m suggest this possibility, since the organisms in the original inoculum were recovered.
  - Another possibility is post-HMC treatment contamination of the tiles and the ability of the tile components to support microbial life.
Acknowledgements

- NASA AES Program Office
- LRR Team from KSC, JSC, GRC, ARC

Mike Ewert, JSC
Jim Broyan, JSC
Paul Hintze, NE-L
Steve Anthony, NE-F
Tony Muscatello, NE-S
Jim Captain, ESC
Bobby Devor, ESC
Doug Tomlin, NE-L
Eddie Santiago, NE-S
Ines Salcedo, NE-I
John Bayliss, NE-L

Gabor Tamasy, NE-M2
David Chesnutt, NE-M1
Kati Zajdel, GP-L
Michele Birmele, ESC
Brian Larson, ESC
Janicce Caro, ESC
Janelle Coutts, ESC
Larry Koss, ESC
Jan Surma, ESC
Thank you for attending!

Do you have any questions for us?

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Mary.E.Hummerick@nasa.gov
General Flow Diagram

Legend:
- FC = Flow Controller
- P = Pump
- PC = Pressure Controller
- PG = Pressure Gauge
- PT = Pressure Transducer
- RV = Relief Valve
- TC = Thermocouple
- TEC = Thermo Electric Cooler
- V = Hand Valve
- Reg = Bottle Regulator
- Tygon tubing
- Gas Chromatography Mass Spectroscopy (GC/MS)
- FTIR
- Vent
- Oxygen rated/cleaned lines
Backup

1st Generation Reactor with Air:
5 SLPM and ~10g of trash

- Recovered Mass (ash + condensable)
- CO2 Yield
- CO Yield
- CH4 Yield
2nd Gen. Reactor Schematic
Fully Integrated Schematic
Minor Products Detected on GC/MS 1st Gen. Reactor

<table>
<thead>
<tr>
<th>CLASS NAME</th>
<th>PROPERTY</th>
<th>REPRESENTATIVE COMPOUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-Undetectable</td>
<td>Very heavy tars</td>
<td>Acetylene, Allene, 1-Butene, 1-Butene-3-yne, Ethylene, Propene, 2-Methylpropene</td>
</tr>
<tr>
<td>ALKENES</td>
<td>Containing at least one carbon-to-carbon double bond</td>
<td></td>
</tr>
<tr>
<td>ALKANES</td>
<td>Consist only of hydrogen and carbon atoms and are bonded exclusively by single bonds</td>
<td>Ethane, Propane</td>
</tr>
<tr>
<td>ALKYNES</td>
<td>Hydrocarbons that have a triple bond between two carbon atoms</td>
<td>Propyne, Ethyne</td>
</tr>
<tr>
<td>ALDEHYDES</td>
<td>R-CHO, consists of a carbonyl center (a carbon double bonded to oxygen) bonded to hydrogen and an R group</td>
<td>Acetaldehyde, 2 propenal,</td>
</tr>
<tr>
<td>CYCLOALKANES</td>
<td>One or more rings of carbon atoms</td>
<td>Methylene cyclopropane</td>
</tr>
<tr>
<td>CYCLIC ETHERS</td>
<td>An oxygen atom connected to two alkyl or aryl groups — of general formula R–O–R'</td>
<td>Ethylene Oxide</td>
</tr>
<tr>
<td>DIENES</td>
<td>Contains two carbon double bonds</td>
<td>1,3-Butadiene</td>
</tr>
<tr>
<td>KETONES</td>
<td>A carbonyl group (C=O) bonded to two other carbon atoms</td>
<td>Acetone</td>
</tr>
</tbody>
</table>