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NEW CONCEPTS FOR WASTE MANAGEMENT SYSTEMS FOR THE LUNAR ENVIRONMENT

Uday Hegde

National Center for Space Exploration Research

Cleveland, Ohio

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OUTLINE

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  - Functions
  - Goals
- Extensible Technologies
- Lunar Research Issues
- Summary
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  - Near Term and Longer Term Applications
- Acknowledgements

Waste Management Benefits

Reduce mission cost and satisfy mission requirements:

- Crew health and safety
- Crew quality of life
- Resource recovery
- Planetary protection – forward protection of Mars for example, and backward protection of Earth (*NASA TM-2006-213485 "Life Support and Habitation Planetary Protection Workshop"*)

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Waste Stream Composition

- Crew metabolic waste
- Food packaging, wasted food
- Brines
- Soiled clothing
- Paper, tape, equipment parts
- Inedible biomass (from plants)

NASA/CR—2004–208941 "Advanced Life Support-Baseline Values and Assumptions Document"

Shuttle data:

Average waste per Crew Member per day (CM-d):

1.39 kg/CM-d (solids)

0.3 kg /CM-d (water)

Potential inedible biomass (food crops) not included in above:

~ 5 kg/CM-d

Waste Management Functions

Basic Functions for Crew Safety and Planetary Protection

- Dispose or Store

-Stabilize waste (e.g., by removing water, gasifying, encapsulating)

- microbial growth is related to water activity a_w (% Equilibrium Relative Humidity/100)

  microbially stable for $a_w < 0.65$

-Reduce volume

-Control odor

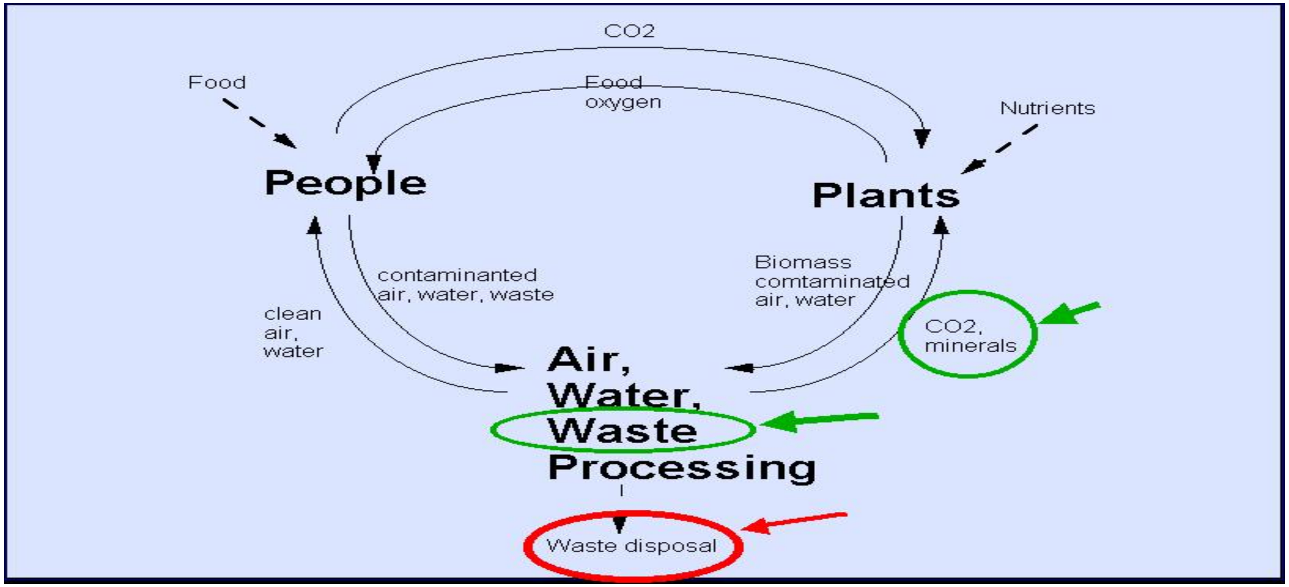
Waste Management Functions (contd)

Advanced Functions for Self-Sufficiency (Habitat)

- Reclaim resources

  -Recover water during drying

  -Reclaim co-products (e.g., for food system, ISRU, radiation protection)



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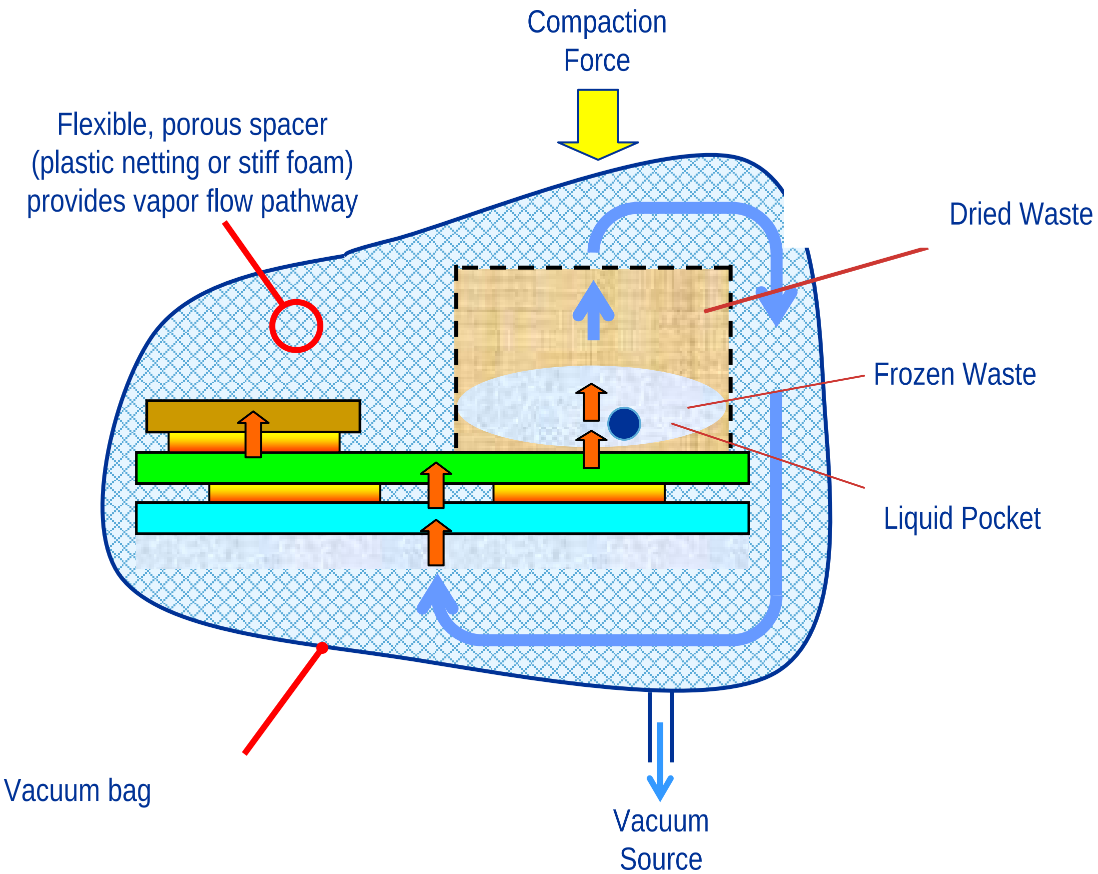
Goals of Waste Management Systems Research

- Enable systems to meet basic function requirements
- Improve safety
- Improve reliability
- Reduce implementation cost e.g., by
  - -optimizing for mass, volume, and power
  - -developing extensible systems to meet additional requirements for advanced functions

Extensible Technologies

Technology	Basic Function	Advanced Function
Vacuum Drying	Waste Stabilization	Water Recovery
Pyrolysis/Gasification	Vent/Dispose	Oxidation and Nutrient Recovery
Compaction and Encapsulation	Volume Reduction/Storage	Radiation Shielding Materials
Supercritical Extraction	Drying of brines	Oxidation and Nutrient Recovery

Stabilize/Dispose/Store ➔ Water Recovery



Thermo-electric Lyophilizer

Litwiller et al, ICES 2007

Heat of sublimation partially recovered from water vapor condensation.

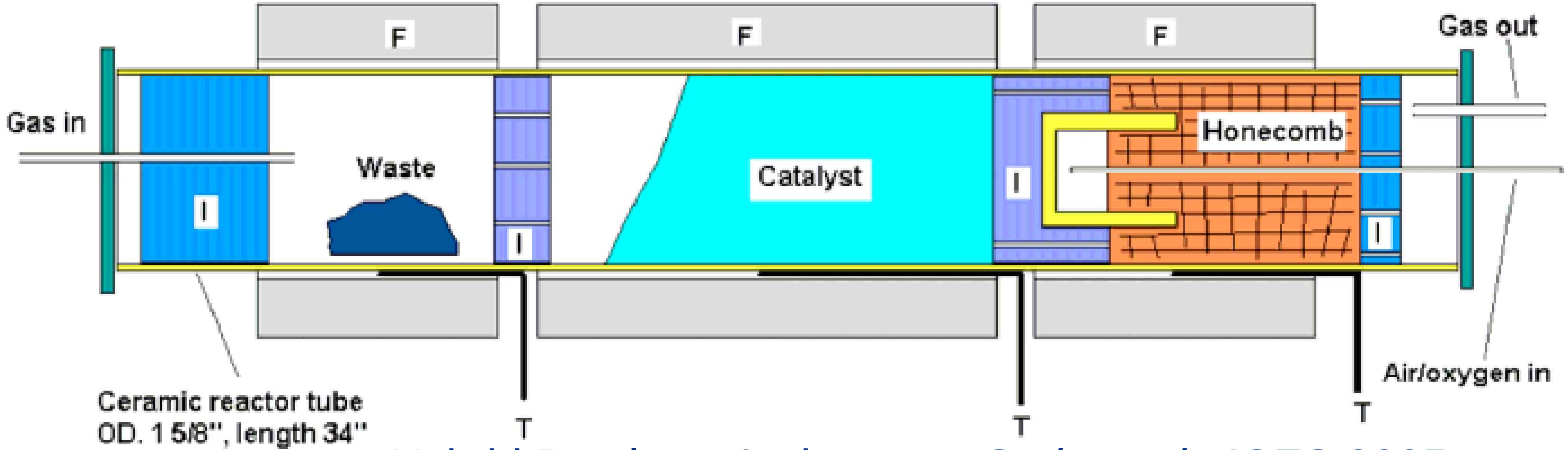
Gasification ➔ Resource Recovery

- Gasification stabilizes waste, reduces waste volume, and allows disposition by venting.

  -pyrolysis: non-oxidative heating of waste

  results in liquid residue/ash of carbonaceous compounds + gases

- Products amenable to further processing for resource recovery

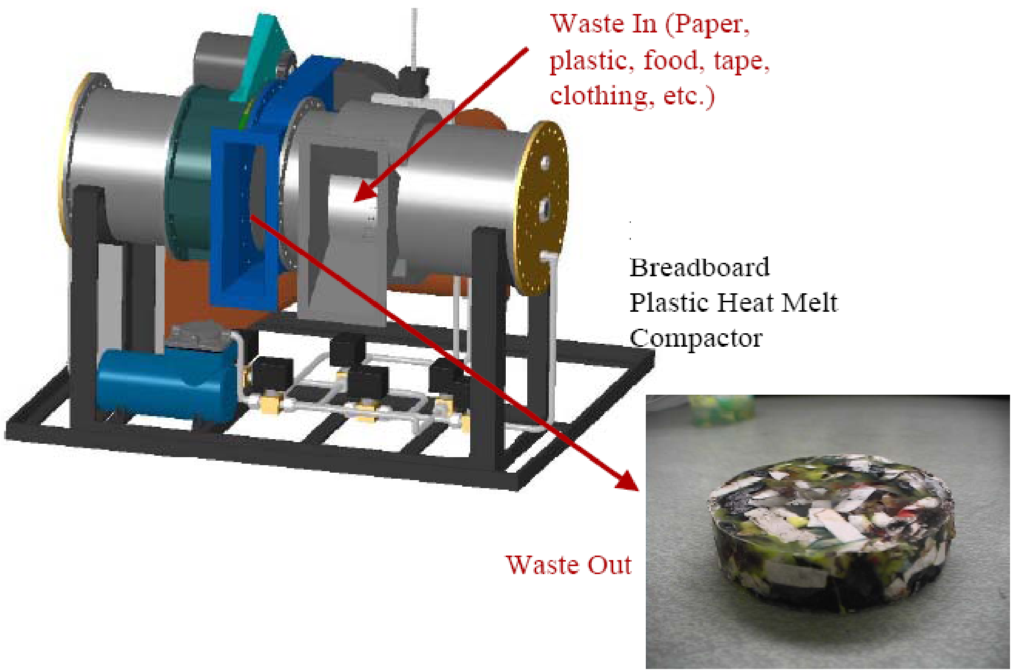


Hybrid Pyrolyzer-Incinerator, *Serio et al, ICES 2005*

Compaction → Radiation Shielding

- Waste compaction to reduce volume
- Plastic melt for encapsulation

Pace et al , ICES 2005



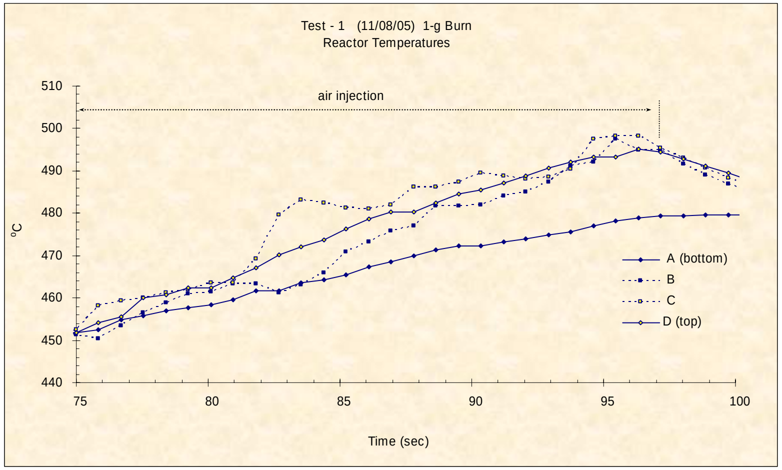
Water Recovery → Resource Recovery

- Removal of dissolved solids from waste water by supercritical water extraction.

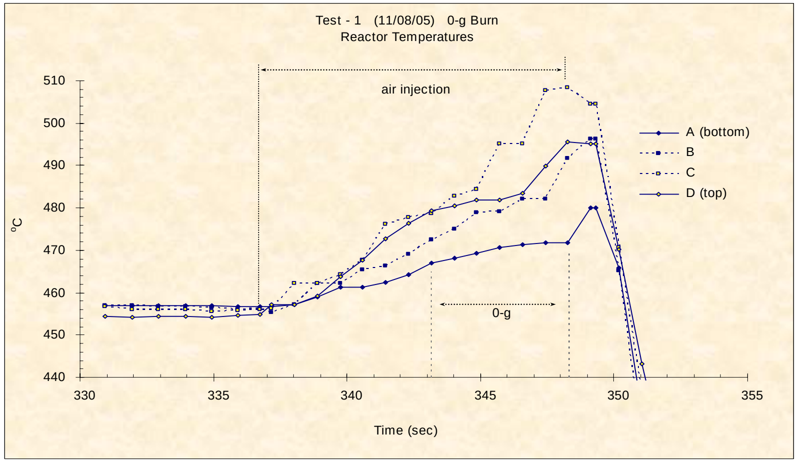
  12% of urine remains as brine after distillation. Recovery of water from brine could yield ~ 400 kg/year for a 6 member crew.

- Supercritical water oxidation of waste for resource recovery

Supercritical Water Oxidation of Methanol showing temperature stratification in low-g . From *Hicks et al, ICES 2006*



1-g



Micro- g

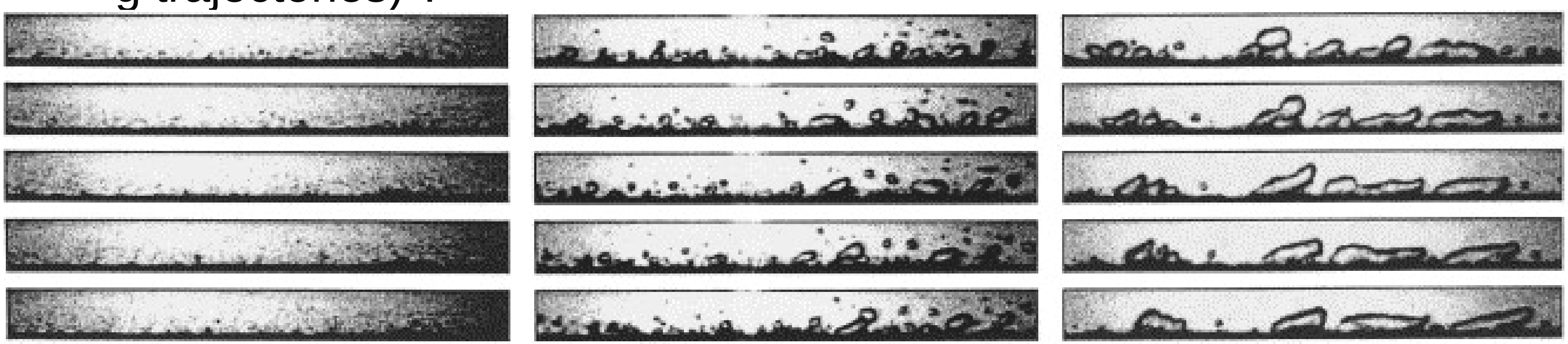
Lunar Research

Why?

1. Obtain database on partial gravity effects on waste management system components (*NASA TM-2004-212940, “Workshop on Critical Issues in Microgravity Fluids, Transport, and Reaction Processes in Advanced Human Support Technology-Final Report”*)

Identify components and/or processes that are affected.

Are the relevant time scales sufficiently small to get statistically significant data on earth-based laboratories (e.g., aircraft flying low-g trajectories) ?



(a) 1.8 g

(b) Lunar g

(c) Micro g

Liquid Vapor Flow (from *Hasan et al, Int J Heat Mass Transfer, 2005*)

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Examples of Relevant Parameters

Grashof Number, Gr	$gL^3\beta\Delta T/\nu^2$	Buoyancy/Viscous
Froude Number, Fr	$(\Delta\rho/\rho)U^2/gL$	Inertia/Buoyancy
Gr/Re^2	$gL\beta\Delta T/U^2$	Buoyancy/Inertia
Dynamic Bond Number	$\rho\beta gL^2/abs(d\sigma/dT)$	Buoyancy/Thermo-capillary

For lunar systems, $g = 1/6\ g_{earth}$, mass and system size (L) are to be reduced => buoyancy effects are significantly decreased.

Stratification, buoyant mixing, surface force effects, multiphase flow regimes are all impacted with implications for design, control, power and operational timelines.

Lunar Research

Why? (contd)

2. Develop verifiable component and system models
   - validate against data

3. Conduct integrated system studies for operation and control
   - component interfaces
   - nearly closed sub-system loops
   - optimize for mass, volume, and power
   - system stability

Top Level Functional Operations

Generation → Initial Storage Container → Processor → Storage/ Disposal

Involves Variable dry/moist/wet solid flows with and without gas phase incorporation

- Collection and Transport
- Storage / Disposal
- Processing (include pre- and post-processing)

Complexity of these operations and gravity related issues will depend upon the overall Solid Waste Management system.

Research Issues
Collection and Transport

- Transport of liquid-solid slurries with or without gas entrainment
- Material containment during transfer to storage systems
- Characterize flow pattern, phase distribution, pressure drop, slurry properties

Research Issues
Storage / Disposal

- Packing and distribution within storage vessels
- Flow through, and emptying from, temporary storage vessels
- Phase positioning within tanks with respect to feed line to reactor and filling port

Research Issues
Processing

- **Solid, Liquid, Gas Feeding Systems**
  - active feed
  - liquid/solid slurry feed
  - gas-solid slurry

- **Drying**
  - water removal
  - water condensation

- **Reactor Design**
  - feed variability and residence time
  - multiphase heating, mixing, and distribution of species
  - manage power (e.g., heat/energy recovery)

- **Phase separation**
  - gas-solid separation (e.g., ash)
  - condenser and water removal

- **Monitoring and control**
  - sensor design and placement

Summary: Significant Concerns

- Reduced buoyant convection for heat and mass transfer, species mixing
- Phase distribution and separation
- Phase change interface propagation
- Multi-phase transport (gravity effects on flow regimes)
- Effects on component/system performance of surface and electrostatic forces
- Power management

Summary: Technologies Development

Near Term (Lunar Sortie)

- Compaction and encapsulation
- Drying/ water removal and recovery
- Gasification/Pyrolysis

Longer Term (Lunar and Martian Habitats)

- Resource recovery technologies

  -Supercritical water oxidation

  -Incineration

  -Biological technologies e.g., composting, microbial fuel cells

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