FIXED PACKED BED REACTORS IN REDUCED GRAVITY

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We present experimental data on flow pattern transitions, pressure drop and flow characteristics for cocurrent gas-liquid flow through packed columns in microgravity. The flow pattern transition data indicates that the pulse flow regime exists over a wider range of gas and liquid flow rates under microgravity conditions compared to 1-g and the widely used Talmor map in 1-g is not applicable for predicting the transition boundaries. A new transition criterion between bubble and pulse flow in microgravity is proposed and tested using the data. Since there is no static head in microgravity, the pressure drop measured is the true frictional pressure drop. The pressure drop data, which has much smaller scatter than most reported 1-g data clearly shows that capillary effects can enhance the pressure drop (especially in the bubble flow regime) as much as 200% compared to that predicted by the single phase Ergun equation. The pressure drop data are correlated in terms of a two-phase friction factor and its dependence on the gas and liquid Reynolds numbers and the Suratman number. The influence of gravity on the pulse amplitude and frequency is also discussed and compared to that under normal gravity conditions.

Experimental work is planned to determine the gas-liquid and liquid-solid mass transfer coefficients. Because of enhanced interfacial effects, we expect the gas-liquid transfer coefficients k_La and k_Ga (where a is the gas-liquid interfacial area) to be higher in microgravity than in normal gravity at the same flow conditions. This will be verified by gas absorption experiments, with and without reaction in the liquid phase, using oxygen, carbon dioxide, water and dilute aqueous amine solutions. The liquid-solid mass transfer coefficient will also be determined in the bubble as well as the pulse flow regimes using solid benzoic acid particles in the packing and measuring their rate of dissolution. The mass transfer coefficients in microgravity will be compared to those in normal gravity cocurrent flow to determine the mass transfer enhancement and propose new mass transfer correlations for two-phase gas-liquid flows through packed beds in microgravity.

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Glenn Research Center

Microgravity Division

Fluid Physics and Transport Branch

Fluid Transport In Advanced Life Support Systems

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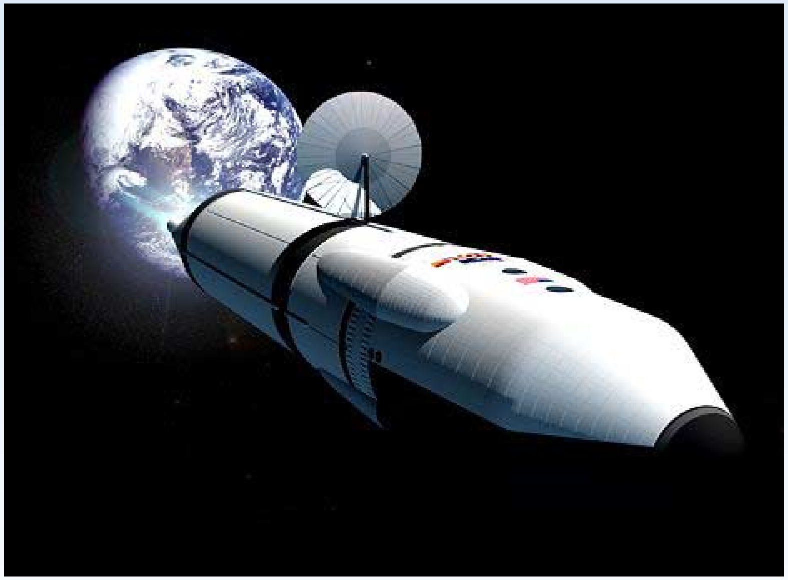
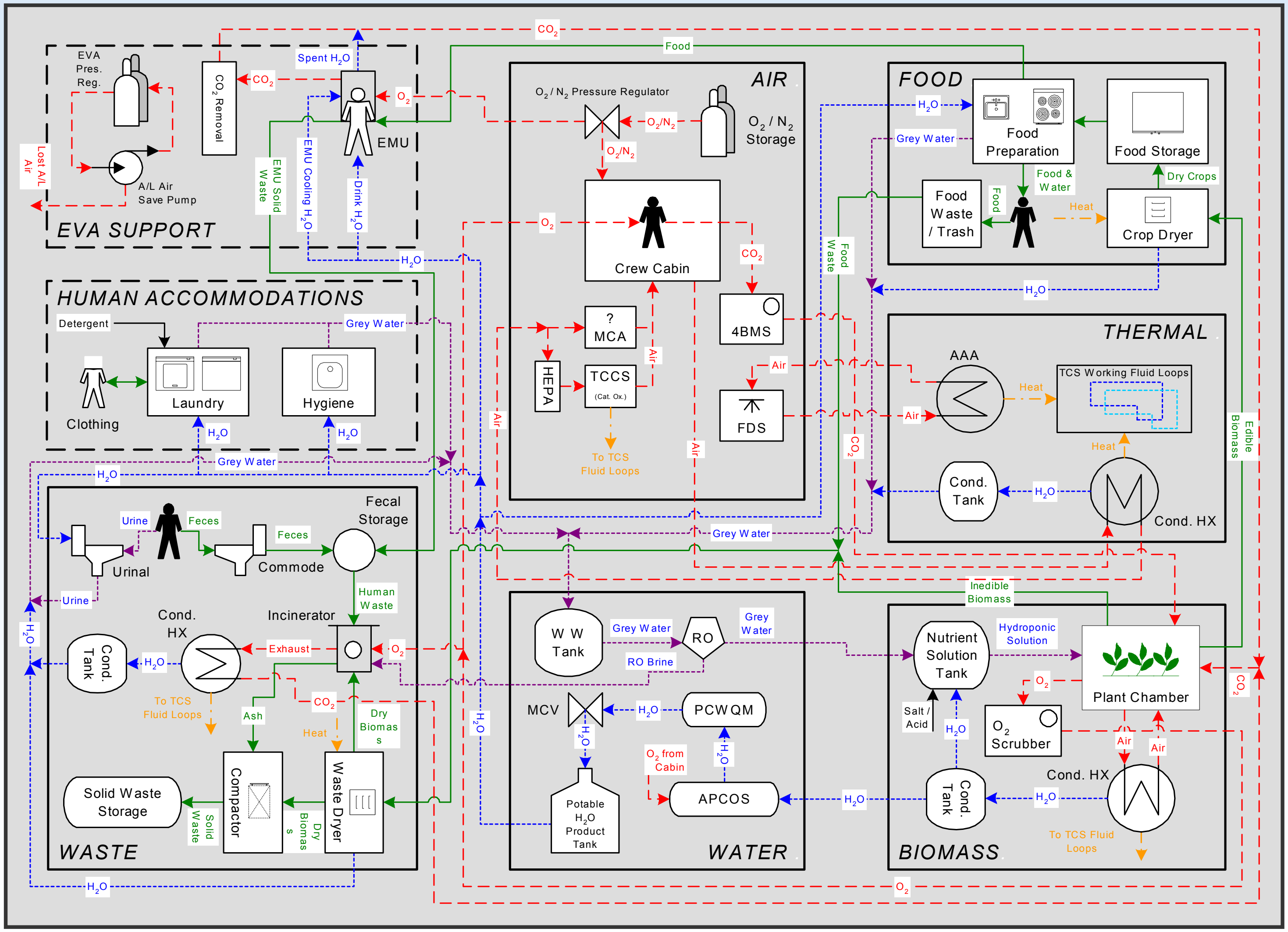
- **Primary challenge is to "close the loop" on the physico-chemical components of basic life support while making them extremely reliable:**
  - Air Revitalization
  - Water Reclamation
  - Thermal Control
  - Solid Waste Management
  - Food Processing
  - Biomass Production
  - Extravehicular Activity (EVA) Support



…with low mass, power and volume.


EVA SUPPORT
EVA Pres. Reg.
CO_2 Removal
EMU
A/L Air Save Pump
Lost A/L Air
Spent H_2O
EMU Solid Waste
EMU Cooling H_2O
Drink H_2O
HUMAN ACCOMMODATIONS
Detergent
Clothing
Laundry
Hygiene
Grey Water
AIR
O_2 / N_2 Pressure Regulator
O_2 / N_2 Storage
Crew Cabin
MCA
HEPA
TCCS
(Cat. Ox.)
4BMS
FDS
To TCS Fluid Loops
FOOD
Food Preparation
Food Storage
Food Waste / Trash
Crop Dryer
Food & Water
Dry Crops
Heat
THERMAL
AAA
TCS Working Fluid Loops
Cond. Tank
Cond. HX
WASTE
Fecal Storage
Urine
Feces
Urinal
Commode
Human Waste
Incinerator
Cond. HX
Cond. Tank
Exhaust
Ash
Dry Biomass
Solid Waste Storage
Compactor
Waste Dryer
Solid Waste
WATER
W W Tank
RO
RO Brine
MCV
PCWQM
Potable H_2O Product Tank
O_2 from Cabin
APCOS
BIOMASS
Nutrient Solution Tank
Hydroponic Solution
Plant Chamber
Salt / Acid
O_2 Scrubber
Cond. HX
Cond. Tank
Inedible Biomass
Edible Biomass
To TCS Fluid Loops
CO_2
O_2
H_2O
Air
Food

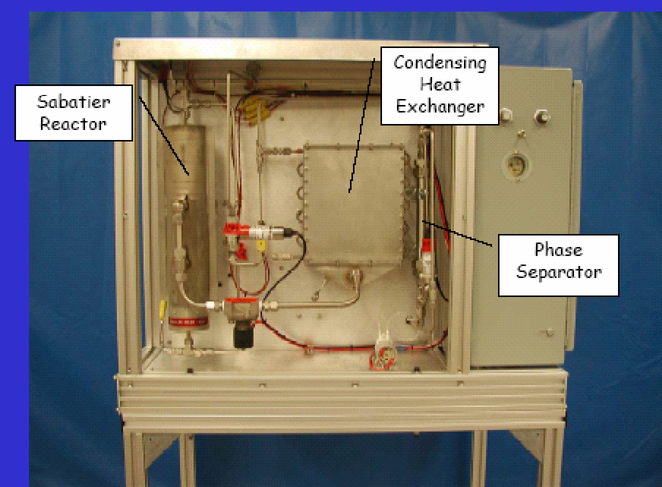
Mission Drives Life Support Requirements

	Lunar Transit Vehicle	Lunar Outpost (LO)	Mars Transit Vehicle	Mars Habitat
Duration (Human Tended) Environment	7 – 14 days (Roundtrip) 0-g	1 – 18 months ~ 1/6-g	12 – 24 months (Roundtrip) 0-g	17 – 20 months ~ 1/3-g
Air Revitalization	Open	Closed 75% by mass	Closed >75% by mass	Closed >75% by mass Resupplied by ISRU
Water Recovery	Collection and Storage	Closed 90% by mass Resupplied by ISRU	Closed >90% by mass	Closed >90% by mass Resupplied by ISRU
Waste Management	Stored	Volume Reduction Mineralization Stabilization Resource Recovery	Volume Reduction Stabilization De-watering	Volume Reduction Mineralization Stabilization Resource Recovery
Thermal Systems	Low Power	High Power	High Power	High Power
Food Systems	Conventional Stored	Conventional Stored with Fresh Food Augmentation	Extended Shelf Life with Fresh Food Augmentation	Extended Shelf Life with Fresh Food Augmentation

Air Revitalization Technologies

- **Carbon Dioxide Removal**
  - Molecular Sieve.
  - Solid Amine Water Desorption (SAWD)
  - Electrochemical Depolarization Concentrations (EDC)
  - Air Polarized Concentrators (APC)
  - Membrane removal and other Regenerative Technologies
- **Carbon Dioxide Reduction**
  - Advanced Carbon Formation Reactor System (ACRS)
  - Bosch
  - Sabatier
- **Oxygen Generation**
  - Electrolysis of water
- **Nitrogen Generation**
- **Trace Contamination Control (TCC)**
  - Particulate Fillers
  - Activated Charcoals
  - Chemisorbant beds
  - Catalytic Burners

Sabatier EDU Front View



Water Recovery Technologies

- **Urine Recovery**
  - Vapor Compression Distillation (VCD)
  - Packed Bed Reactor (PBR)
  - Thermoelectric Integrated Membrane Evaporation System (TIMES)
  - Air Evaporation Systems (AES)
  - Aqueous Phase Catalytic Oxidation Post
  - Supercritical Water Oxidation (SCWO)
  - Vapor Phase Catalytic Ammonia Removal (VPCAR)

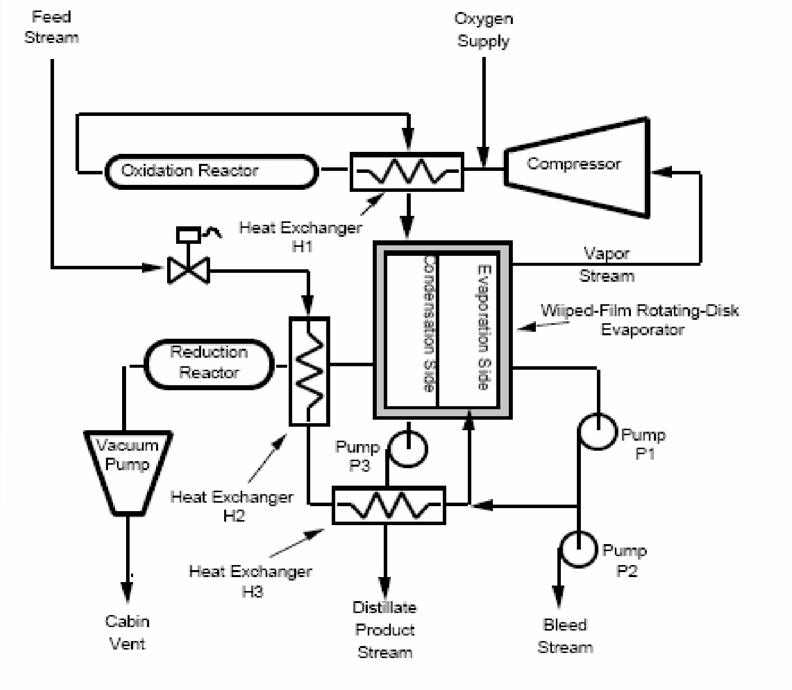


Fig. 1. VPCAR process flow diagram.

- **Hygiene Recovery and Potable Processing**
  - Reverse Osmosis (PO)
  - Multifiltration (MF)
  - Electrodialysis

- **Water Recovery from Condensate**
  - Condensation/Separation

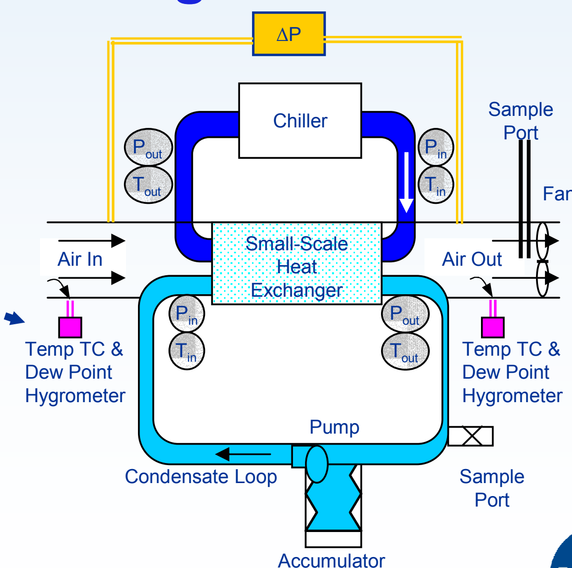
Solid Waste Management Technologies

- **Collection, Segregation, and Storage**

- **Solid Waste Treatment (stabilization)**
  - Super Critical Water Oxidation
  - Wet Oxidation
  - Combustion/incineration
  - Electrochemical incineration

Thermal Control Technologies

- **Air Temperature and Humidity Control**
  - Condensing heat exchanger/moisture removal
  - Air heat exchanger



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Fluid Transport and Reaction Processes

- *Fluid management, transport, and reaction processes are common and critical to many of the ALS subsystems – leading to the following questions...*
  - *What are the direct or indirect effects of microgravity on systems that are most critical to the development of ALS?*
  - *Can closed loop systems (or even components) be developed that are truly gravity independent?*
  - *If so, how will independence be verified?*
  - *If not, how will long term verification and testing be conducted?*
  - *What system level modeling is needed and how do we verify the models?*
  - *How can the microgravity environment be leveraged to enhance the operation of ALS?*
  - *Can these systems be operated in a variety of gravity environments?*
- *NASA is developing a systematic program of investigation to identify the fluid transport issues relevant to life support.*
  - *Program leverages both internal and external experts from Code UG programs.*

✓ ***First step - identify specific critical areas of research with the greatest potential for successful resolution.***

- Fine Particulates (May 5-7, 2003): *Identify problems associated with the control of fine particulates in closed-loop systems.*
  - *26 invited participants http://www.ncmr.org/events/particulate/*
- Two-Phase Flow, Fluid Stability and Dynamics (May 15, 2003): *Prioritize strategic research thrusts related to multiphase flow of spacecraft power, propulsions and advanced life support systems.*
  - *48 invited participants http://www.ncmr.org/events/multiphase/*
- Microgravity Fluids, Transport and Reaction Processes in Advanced Human Support Technology (August 11-13, 2003): *Identify and prioritize fluids, transport and reaction problems associated with AHST and develop strategic collaborative investigations.*
  - *52 invited participants*

Summary of Workshop Findings

- Recommended increase collaboration by involving microgravity program in early development of AHST through final on-orbit testing.
- NASA should take lead in compiling design guides detailing fundamental mechanisms and predictive tools (models, correlations, etc.) relative to AHST.

Air Revitalization

- Determine particulate matter size distribution on ISS (< 10 microns)
- Coordinate effort to understand fire signatures
- Develop packed beds for CO_2 removal
- Develop phase separation and liquid degassing techniques for ECLSS.

Water Recovery

- Develop 0-g models and correlations for multiphase flow and separation
- Continue technology development for packed bed reactors in 0-g
- Obtain techniques for accurate multiphase metering/sampling
- Develop technology for fixed film (or other types) bioreactors
- Develop technology for phase change/evaporation systems

Summary of Workshop Findings

(Continued)

Thermal Systems

- Attain a phenomenological understanding and accumulate pertinent empirical data for two-phase flow systems.
- Develop advanced, efficient, and reliable vapor compression heat pump technologies.
- Develop reliable and low cost dynamic pressure control mechanisms for liquid storage tanks (eliminate venting).

Solid Waste Management

- Develop handling and transport of solid waste.
- Models for two- and three-phase flow for very low and very high moisture content.
- Develop monitoring and control systems.

✓ *Second step – propose gravity dependent technologies to develop with other NASA Centers.*

- Develop predictive/design models and technologies for mitigation of particulate build-up in closed-loop systems (minimize generation, transport, and deposition).
- Develop technologies to monitor and characterize fine particulates.
- Develop models and correlations for bed reactor technology in hypo-gravity.
  - Gas-liquid reactors (fixed or moving)
  - Minimize or eliminate fine particulate generation in fixed PBR (single phase).
- Develop empirical correlations, theoretical models, scaling laws and comprehensive CFD codes for hypo-gravity environment:
  - Two-phase flow in complicated geometries (components, tees, fittings, etc.)
  - Boiling and condensation heat transfer (CHF)
  - Phase distribution and phase transition
- Develop stability criteria for two-phase systems in microgravity.
- Develop advanced phase separation technologies.
- Develop gas-tolerant liquid pump.

➢ *Third step - implement recommendations through ground and flight (ISS) based programs.*

ISS FLIGHT

- Two Phase Flow Facility (ToFFy): Flow Boiling, Condensation, Phase Separation, System Stability
- AHLS-1: Reactor technologies: Fixed and Moving Beds
- AHLS-2: Condensing Heat Exchanger for Space Systems (CHESS)
- AHLS-3: Two-Phase/TBD

- LMM (CVB), BXF (MABE, NPBX), LME, MOBI, CCF

GROUND BASED

- Complete existing grants – capitalizing on the “strategic” value.
- Phase in new longer-term ALS R&D through baseline and augmented budgets.

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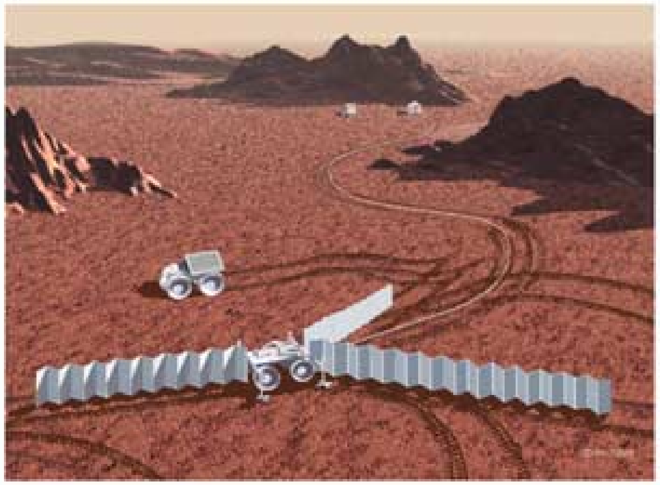
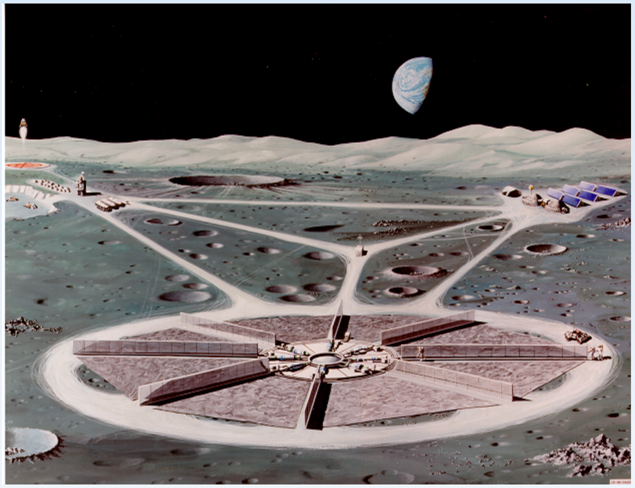
Glenn Research Center's Role in ALS





- ***Develop specific components, subsystems, and technologies where the gravitational dependence of fluids, transport and reaction processes are on the critical path to the overall development of ALS systems.***

- ***Provide key design tools, experimentally validated components, trade studies and necessary "trouble shooting" as flight systems are developed.***