The Packed Bed Reactor Experiment (PBRE-2 and PBRE-WR)

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Background

- PBR: chemical or biological reactor vessel filled with fixed solid particles, flowing any combination of gas and liquid reactants or products through the packing.

- Solid packing: various shapes and sizes, serves as support for catalyst or host for bio-growth material.

- PBR: most common type of reactor used in industry today (~80%).

- Advantages: higher throughputs, compact design, operational flexibility and minimal power consumption – excellent candidate for long-duration human space flight.

- Challenges: fouling, pressure drop, flow stability, flow regimes, catalyst degradation, scale-up, heat and mass transfer.

- Provides opportunity to purify/treat water in space (examples provided in later charts).
Types of Reactors

Chemical/Biological Bed Reactors

- Suspended
  - Slurry
  - Fluidized

- Fixed
  - Two-Phase
    - Liquid
      - Continuous
        - Bubble
    - Gas
      - Continuous
        - Trickle
          - Gravity Driven
        - Spray/Mist
          - Inertia Dominated

Single-Phase (but 2-phase in startup or recovery)

Pressure traces

Packed Bed Reactor Experiment
Introduction

Increment 61 & 62 will provide the opportunity to re-fly the PBRE experiment within the Microgravity Science Glovebox.

PBRE-1 completed ops in MSG (2/2017).

- Included glass and Teflon packing.
- Some hardware issues reduced some of the original science (mainly with high speed video) – has been resolved for re-flight.

PBRE-2 will extend test matrix to different size packing.

PBRE-WR will extend test matrix to different type of packing (alumina).
Investigation Goals & Objectives

- Investigate the role and effects of gravity on gas-liquid flow through porous media. Specific NASA applications include chemical and biological reactors for water revitalization as well as flows to deliver water and nutrients to plant systems.

- Develop/validate scaling laws and design tools for future fixed packed bed reactors in 0-g and partial-g environments, including start up and transient operations.

- Identify strategies to recover single phase beds from undesired gas bubbles.

- Provide test fixture for future two-phase flow components (e.g. membrane beds).

- Develop and validate gas holdup models such as B. Guo, D.W. Holder & L. Carter, Physics of Fluids (2004).

- By removing the influence of gravity in flow through porous media, study the effects of other important forces such as inertial, viscous and surface tension forces.
ISS Test Matrix

Packed Bed Reactor Experiment
Current & Future Life Support Systems

Packed Bed Reactor Experiment

- Final porosity BWP
- Initial porosity BWP
- IVGEN & APCO
- Lowest Gas/Liquid Flow Rates on Aircraft (water)
- Single Phase Ergun Equation

- Ion X-Ca+2
- VRA
- ACTEX
- OGA

- Startup flow rates

\[ f = \frac{\text{Re}_{LS}}{(1 - \eta_L)} \]
Full range of gas (nitrogen) and liquid (water) flows anticipated in thermal and life support systems. Testing spans two orders of magnitude of Liquid and Gas Reynolds Number.

- **Gas flow**: 0-1 kg/hr
- **Liquid flow**: 0-150 liters/hr
  - Includes identification of minimum liquid flows to expel trapped gas pockets.

Critical diagnostics and data collection. Capability to add/upgrade diagnostics.

- 2 high speed video cameras
- 5 high speed pressure transducers spaced evenly along column

Interchangeable beds (up to 24 inches long by 5 inches in diameter).
Water Recovery Systems (WRS)

- Water Processor Assembly (WPA) uses a thermal catalytic reactor for oxidizing volatile organics
- Single-phase packed beds
  - Microbial Check Valve (MCV), an iodine addition system
  - Activated Carbon/Ion Exchange (ACTEX), an iodine removal system
  - WPA Multifiltration Beds use adsorbent and ion exchange media for removal of dissolved contaminants
WRS Developing Technologies with Packed Beds/Membranes

- Direct Osmotic Concentration (DOC) System
  - Forward/Reverse Osmosis membranes: processes hygiene/laundry wastewater
  - Direct Contact Membrane Distillation: processes urine/humidity condensate
  - Aqueous-Phase Catalytic Oxidation: post-processing

- Biological Water Processors
  - Pretreatment: hollow-fiber membranes
  - Primary processors: packed beds
Medical:

- IntraVenous Fluid GENeration (IVGEN): demonstrated a microgravity compatible water purification and pharmaceutical mixing system.
- Successfully flown in March, 2010.
- PBRE model was used to predict deionizing resin bed startup conditions and pressure drop.
- Required minimal liquid velocity to clear bubbles from packed bed and minimal flow rate to meet purified water production requirements.
Expected Results

- **PBRE-2**
  - Re-flight with smaller packing to increase pressure drop across column.
  - Obtain full set of video data to determine flow regimes (camera malfunction experienced on initial flight).
  - Validate pressure drop models with smaller packing size.

- **PBRE-WR**
  - Establish pressure drop and gas occlusion for various gas/liquid flow rates over the potential range for the reactor application
    - Data will subsequently be used to optimize reactor design
  - Establish pressure drop for gas/liquid flow rates consistent with PBRE-2 to develop correlation for different packing material