Gas-Liquid Flows and Phase Separation
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Common Issues for Space System Designers

- Ability to Verify Performance in Normal Gravity prior to Deployment.
- **System Stability**
- Phase Accumulation & Shedding
- **Phase Separation**
- Flow Distribution through Tees & Manifolds
- **Boiling Crisis**
- Heat Transfer Coefficient
- Pressure Drop

* Two Phase Flow Facility
Partial Listing of Where Gas-Liquid Flows are in Life Support Systems

<table>
<thead>
<tr>
<th>Stream Type</th>
<th>Air Revitalization</th>
<th>Water Reclamation</th>
<th>Thermal Management</th>
<th>Solid Waste Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabin Humidity Condensate</td>
<td>√</td>
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<td>√</td>
<td></td>
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<tr>
<td>Urine</td>
<td></td>
<td>√</td>
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<tr>
<td>Spills</td>
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<td>√</td>
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<tr>
<td>Dish Washing</td>
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<tr>
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<td>Waste Solids Drying</td>
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<tr>
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Life Support Systems

- **Commonality of Source Stream**
  - Aqueous-based Working Fluid (Water)
  - Into Waste Water Tank
  - Low Pressure Inlet
  - Gas Phase Present
  - Particulate Matter may be Present

- **Differences**
  - Dissolved Matter $\rightarrow$ Fluid Property Effects
  - Batch vs. Continuous Input
  - Flow Rates
  - Void Fraction
Thermal Management Systems

Heat Source Temperature

$T \approx 50 \degree C$

$Q \rightarrow$

$T_{Source} > T_{Radiator}$

Pumped Loop

$Q \rightarrow$

$T_{Source} < T_{Radiator}$

Vapor Compression
Vapor Compression Cycle

Two Phase Issues

- Condenser
- Evaporators
- System Stability
- Flight Demo
- 2Ø Separator
- Parallel Channel Instability
- 2Ø ΔP & Heat Transfer Coefficient
- Liquid Droplet Carryover
- Lubricant Management
- 2Ø Phase Change
The Effect of Reduced Gravity on Gas-Liquid Flows

Negating the Effect of Buoyancy

- Axisymmetric flows
- Reduced Hydrostatic Pressure
- Spherical Bubbles vs. Ellipsoid
- No Gravity-Induced Shearing:
  - Gas Phase Rising relative to Liquid Falling
- Co-flow of Gas and Liquid Phases.

Radial void fraction distributions

- □ upward
- △ downward
- ○ microgravity
What Do We Know?
Flow Regimes

• 3 (½) Flow Regimes: Bubble, Slug, Annular
  (Transitional Slug Annular)
• Multiple Models that work well
  – Constant Void Fraction
  – Weber Number Model
  – Suratman Number Criteria
What Do We Know?
Pressure Drop

- Modified Homogenous Equilibrium Model works well
  - Mixture Density
  - Mixture Velocity
  - Liquid Viscosity
Wall Friction Factors $f_L$ in Bubbly Flow:

Reduced Gravity Two Phase Flow:
- $D=6$ mm, □ $D=10$ mm, △ $D=19$ mm,
- ■ $D=12.7$ mm, ○ $D=40$ mm

Single-Phase Flow:
+ $D=6$ mm, _ $D=10$ mm, - $D=19$ mm

Blasius, Poiseuille relationship
Concerns

- Phase Accumulation and Shedding
  
- Liquid Film Rupture and Dryout
Example: Sabatier Reactor

\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2(\text{H}_2\text{O}) + \text{heat} \]

2Ø Issues
- Separator
- Liquid in Gas Outlet Stream
  - Detection
  - Response
- Influence of Fines
Crew Exploration Vehicle
Thermal Management System

- Capsule-type vehicle
- Functional during Orbital, Re-entry, and Post-Landing Phases
- Closed Loop System – Desire No Flash Evaporators
- Heat Load Estimate
  - Fuel Cells: 7 kW at 50 °C
  - Electronics: 3 kW at 40 °C
  - Cabin: 0.5 kW at 7 °C
- Limit Total Radiator Area < 200 ft²
- Body Mounted Radiator
- Working Fluid
  - Non-Toxic
  - Non-Corrosive
  - Low Freezing Point
Why Separate?

- Critical Process or Component that is intolerant of one Phase
  - Centrifugal pumps with gas bubbles
  - Phase Specific Sensors, i.e., hot wires
  - Biological media negatively impacted by gas

- Better System Performance
  - Condensers Work Better if no liquid present at inlet.
  - Control of Phase Distribution into a manifold
Requirements to Consider

- **Available Power**
  - Mars Transfer Vehicle has MW but for propulsion
  - CEV has up to 10 kW
- **Vibration**
  - Wear & tear
  - Noise
- **System Life**
  - Most will be Life of Mission or Vehicle
  - Some systems may have cleanliness/sterile concerns
- **Separator Life**
- **Flow Rate range**
  - ml/min to l/min
Requirements to Consider

• **Acceleration Environments**
  – Pre Launch 1 G
  – Launch – hi-G’s
  – Transit - microgravity
  – De-Orbit – hi-G’s
  – Moon (1/6 G) or Mars (3/8 G)
  – Post Landing 1 G

• **Degree of Separation Desired**

• **Contamination Sensitivity**
  – Separation process negatively impacted by solids or immiscible 2nd liquid phase

• **Tolerance of “Slugging” or “flooding” Events**
  – System capacitance

• **Startup & Shutdown**
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Mechanical Phase Separation

- Centrifuge – Very high G’s
  - Spin outside housing
  - Spin internal float
- Use rotational acceleration to also develop “hydrostatic” pressure rise to pump liquid
  - Rotary Fluid Management Device (Sundstrand)
  - Two Phase Pump (Foster-Miller)
  - MOBI
Passive Separation: Membranes

- Use of Hydrophilic Membranes and Surfaces to position liquid interface and withdraw liquid.
- Liquid Acquisition Devices (LAD’s) are used in upper stage propellant tanks to ensure start of rocket motor.
- Gas Phase Breakthrough based on bubble point or LaPlace Eqn using membrane pore size.
- Prone to contamination.
Passive Separation: Inertial

- Phase Separation achieved due to inertial differences in liquid and gas phase inertia

Bubble Flow through Tee

Gas Accumulation in Vena Contracta
Passive Separation: Inertial

- Phase Separation achieved due to inertial differences in liquid and gas phase inertia
Passive Separation: Cyclonic

- Two Phase Flow Injected Tangentially into Cylinder.
- Separation driven by Flow
- Cyclones designed for microgravity will work well in multiple gravity levels
Summary

- Guidance similar to “A design that operates in a single phase is less complex than a design that has two-phase flow”\(^1\) is not always true considering the amount of effort spent on pressurizing, subcooling and phase separators to ensure single phase operation.
- While there is still much to learn about two-phase flow in reduced gravity, we have a good start.
- Focus now needs to be directed more towards system level problems.

References

- Low Gravity Two Phase Flow Movies
  http://microgravity.grc.nasa.gov/6712/2phase_flow/2phase.html