A Preliminary Assessment of Phase Separator Ground-Based and Reduced-Gravity Testing for ALS Systems

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Outline

- Multiphase Flow Technology Program
- Types of Separators
- MOBI Phase Separators
- Experiment set-up
- Preliminary comparison/results
- Conclusions

Multiphase Flow Technology Program

- *Demonstrate Phase Separator Technologies*
  - *Control liquid and vapor phases flow & distribution to ensure stable operation of two-phase systems*
  - *Can also be used to optimize performance by removing uncertainty with regards to flow regime effects, e.g., flow distribution in parallel condensers*
- Demonstrate Gravity-Independent Flow in Components Throughout the System
  - Enables 1-G verification of Component Performance
  - Enables operation in vehicles subjected to a variety of gravity environments encountered during different mission phases including launch, coast, descent, and surface operations.
- Quantify the Thermal Hydraulics of the Boiler/Evaporator.
  - Maximize the amount of vaporization to ensure no liquid droplet carryover from evaporator
  - Boiling nucleation and Flow Regime Transitions can thermally fatigue boiler/evaporator walls
- Demonstrate System Stability
  - Integrated system behavior/phenomena may differ from interaction between components as has been demonstrated on terrestrial systems
  - System startup, shutdown, and changes in set point operation

Multiphase Flow Technologies-Why NASA?

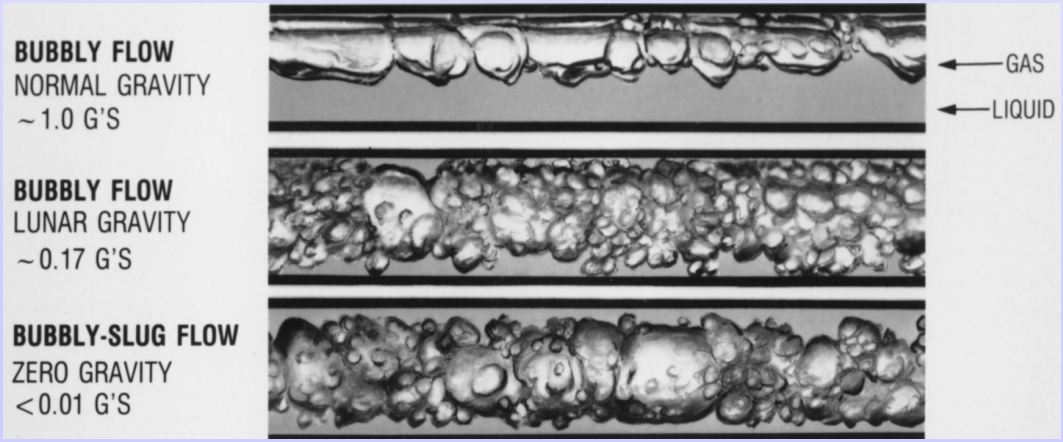
NASA unique system requirements for human exploration missions demand long duration life support, increased power, and increased thermal rejection along with lower mass and higher reliability.

Multiphase flow and heat transfer technology on Earth have been empirically based. The design rules and correlations used on Earth are largely invalid for a microgravity environment.

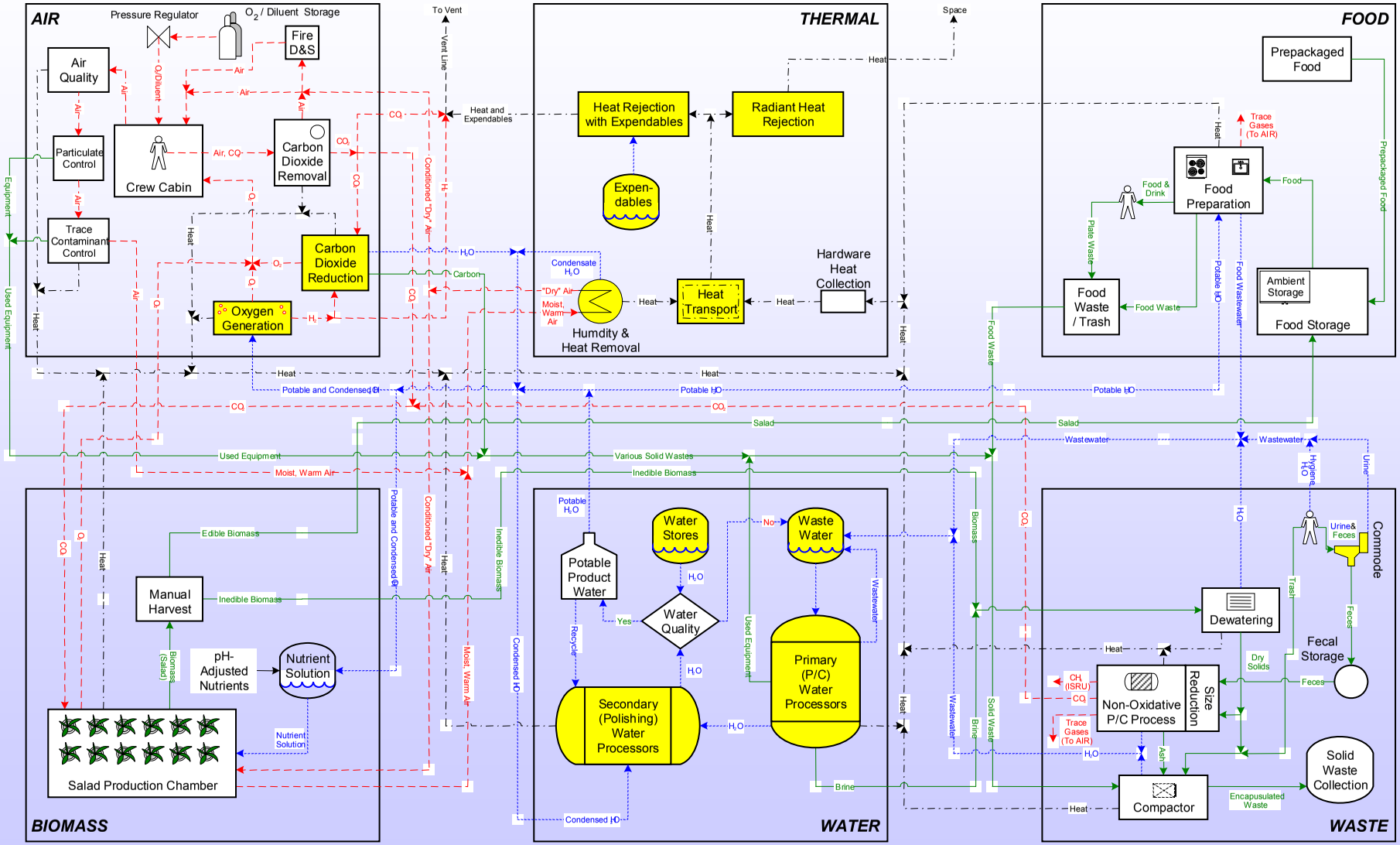
Why Two Phase Systems:

Supports Constellation Development

- Enhance the heat-load-to-weight ratio by better than an order of magnitude
- Enables the use of structural radiators because of elevated heat rejection temperatures
- Lower mass, lower power requirements due to smaller pumps and decreased fluidic volumes

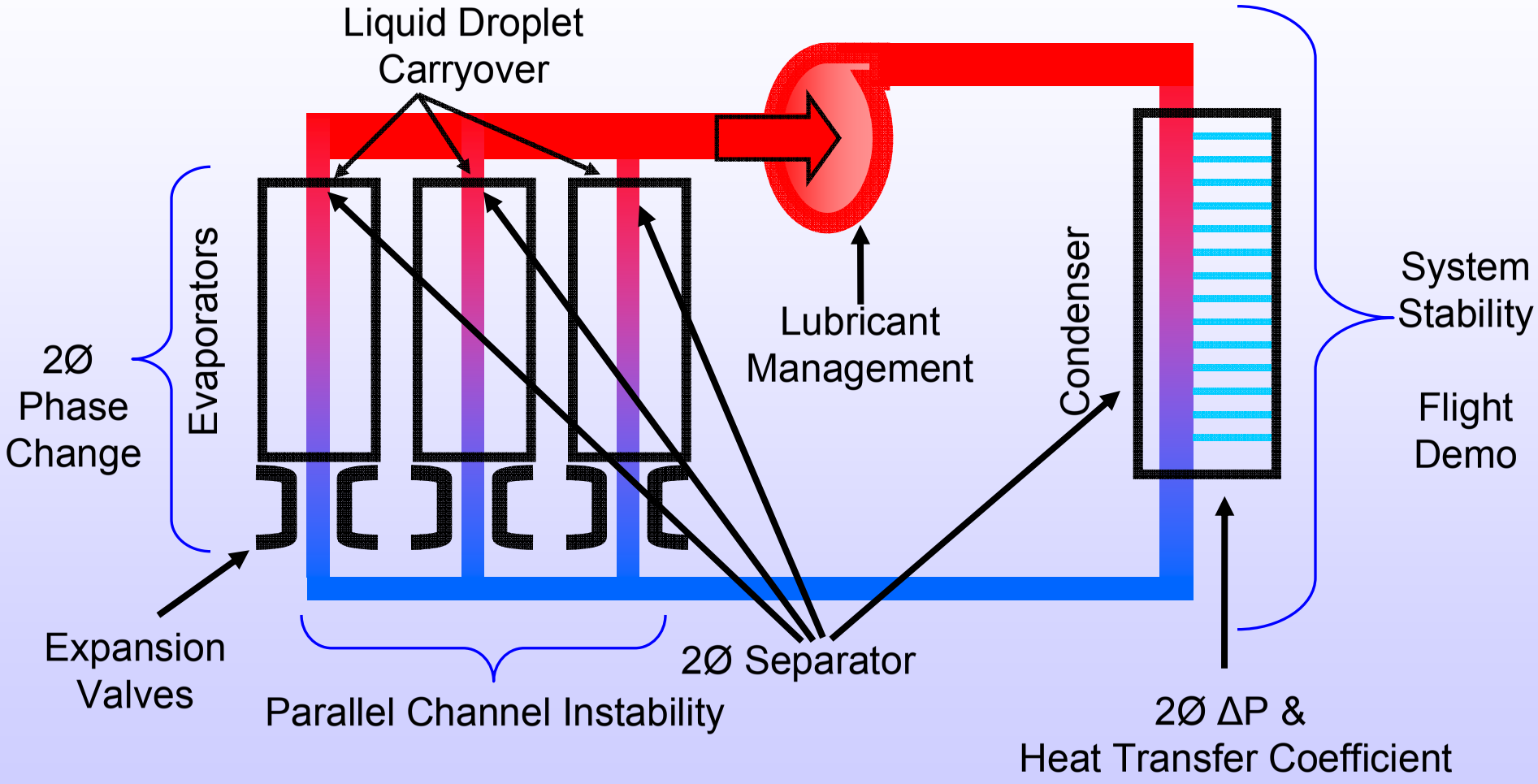


Systems using Multiphase Technologies



Sample Application-Mars Transit Vehicle Life Support System

Vapor Compression Cycle - Two Phase Issues



Active Phase Separators

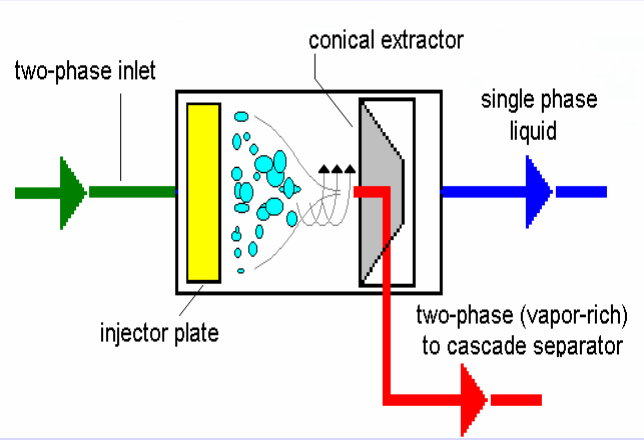
- Generally more massive, require more power to operate, and raise issues with regards to rotary seals and reliability.
- Types of active Separators
  - Centrifugal
    - Rely on centrifugal acceleration generated by rotating a portion of the separation
  - Electrohyrodynamics (EHD)
    - Difference in dielectric constant between vapor and liquid
  - Ultrasonic
    - Contains an active element that vibrate

Passive Phase Separators

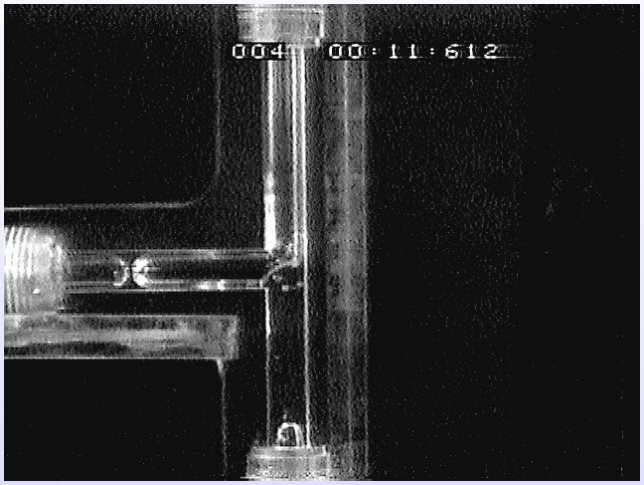
- Offer the advantage of no moving parts, long life and require low power to operate, but are more susceptible to disruptions from design and upset operational conditions
- Types of Passive Separators
  - Cyclonic or vortex Separators
    - Injects 2 phase mixture tangentially to generate a cylindrical volume
  - Capillary-based separators
    - Uses the wetting properties of the fluids to effect the separation
  - Inertial Separators
    - The density differences between the gas and liquid phase are exploited in buoyancy driven separators in 1g
    - The density differences effects the differences in the inertia between two phases in reduced gravity.

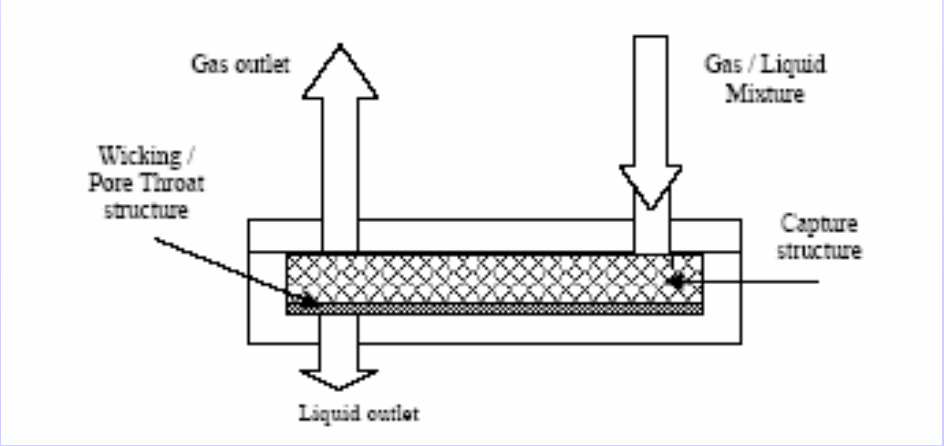
Types of Passive Separators

Schematic of Vortex Separator



Inertial Separator: Gas-Liquid Slug flow through a Tee. flow is from bottom and exits to the left and the top. →





Schematic of Capillary based Separation Device

Passive and Active Gas-Liquid Separation Devices Project

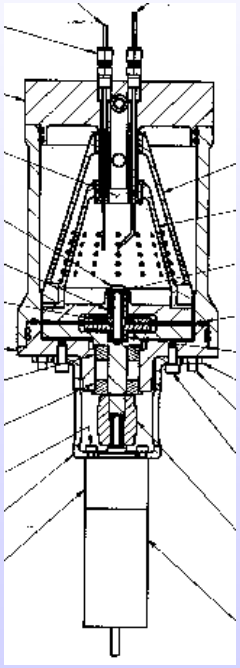
- Objectives
  - Research and test active and passive phase separation devices covering a wide range of Advance Life Support (ALS) areas in order to determine water and gas flow rates and gas volume fractions applicable to each ALS system identified.

- Reality
  - Scope of project reduced so only active phase separators were tested on a rig that was shared with the Gas Tolerant Liquid Pumps project.
  - Testing performed on the Microgravity Observations of Bubble Interactions (MOBI) phase separator along with a modified version of it and miniature version.
  - Low gravity testing was not possible at this time due to the unavailability of the reduced gravity airplane so only ground-based were performed.

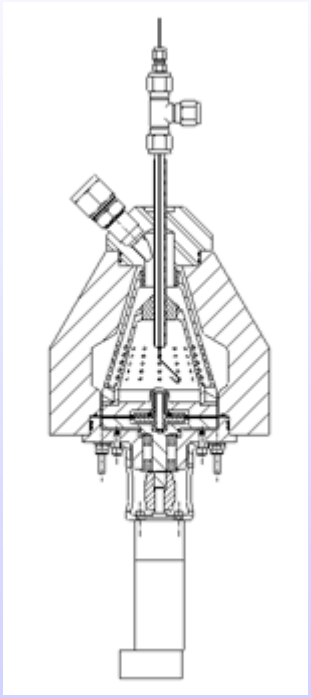
Issues associated with the performance of active and passive separators in microgravity environment

- Weight
- Power Consumption
- Reliability
- ➢ Startup/Shutdown
- ➢ Response to System Instabilities
- Susceptibility to Fouling

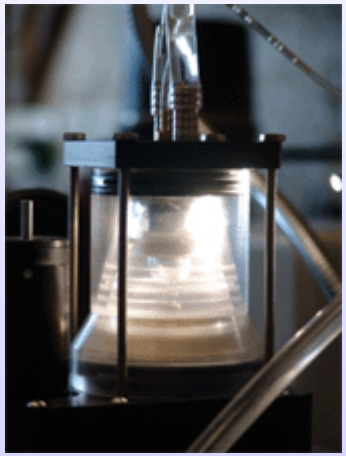
Phase Separator Designs



•Original MOBI
•Cylindrical housing



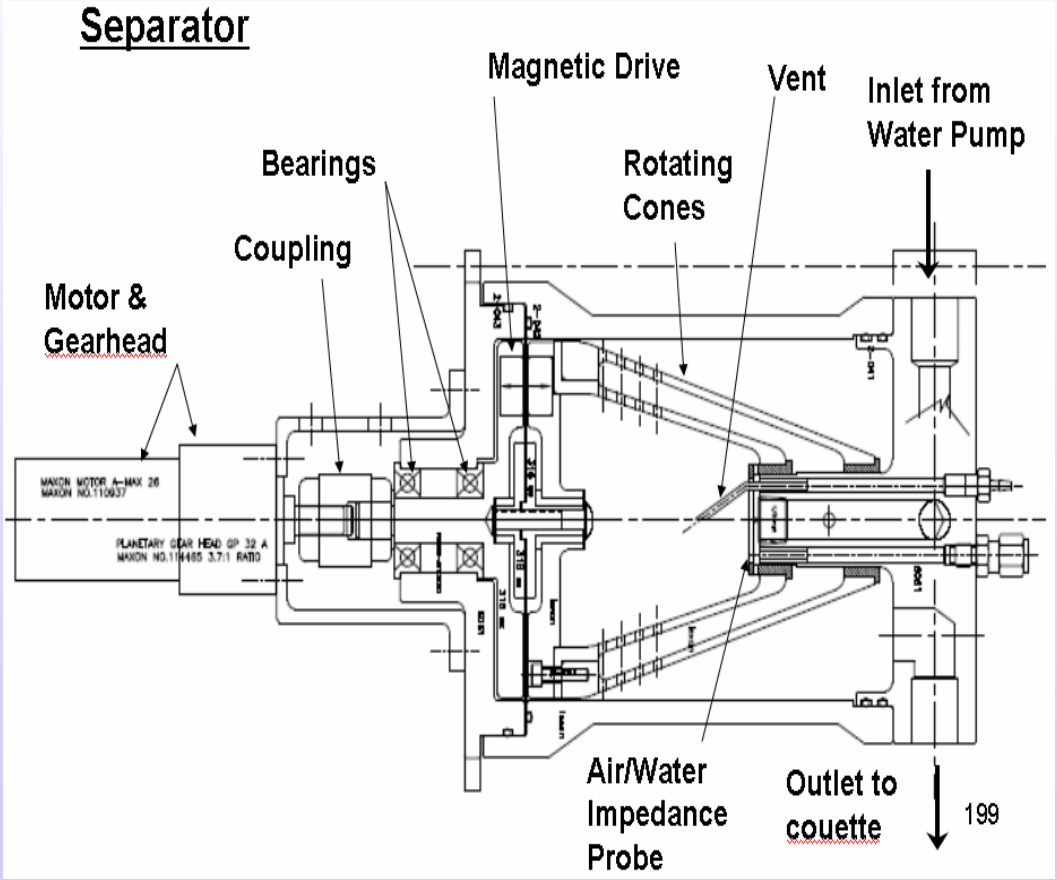
•Modified MOBI
•Conical-shaped housing
•Water outlet moved from the top
•Alloy steel bolt h/w



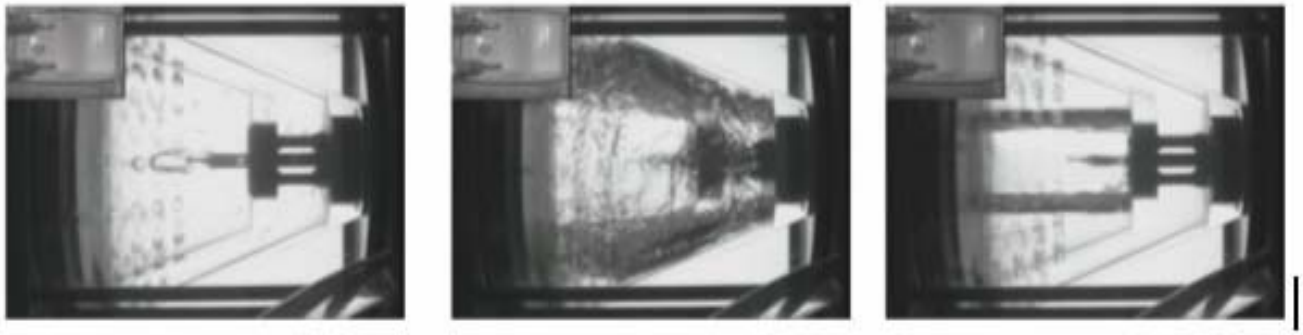
•Miniaturized MOBI
•Separator Housing is 11.25cm x 12.5cm x 8.75cm

Original MOBI phase separator

- Two phase fluid is pumped to centrifugal separator from side inlet
- Separator rotates at 2400 rpm
- Gas core vented through a solenoid valve
- Air/Water detector (based on the impedance probe design) used to control solenoid valve

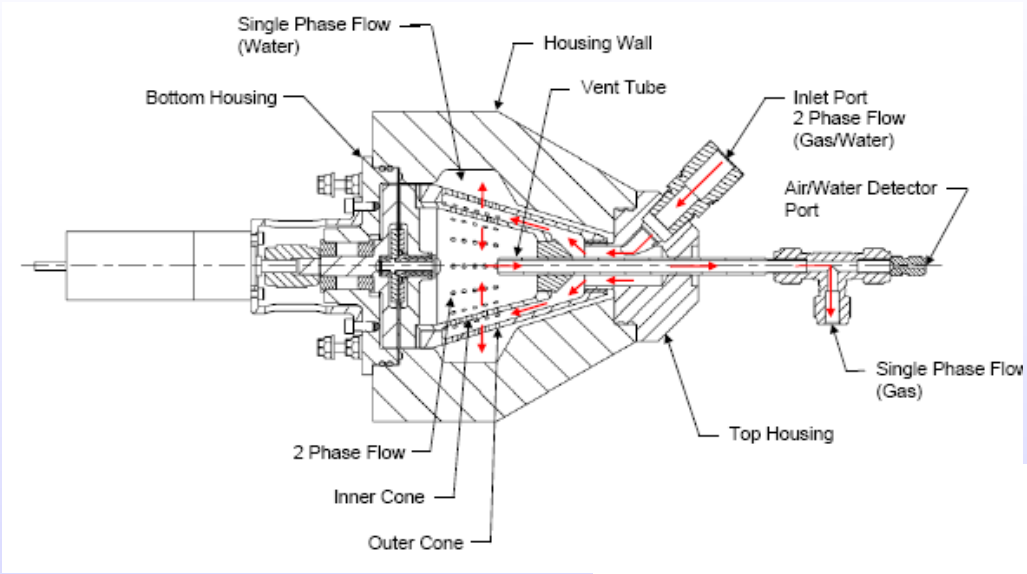


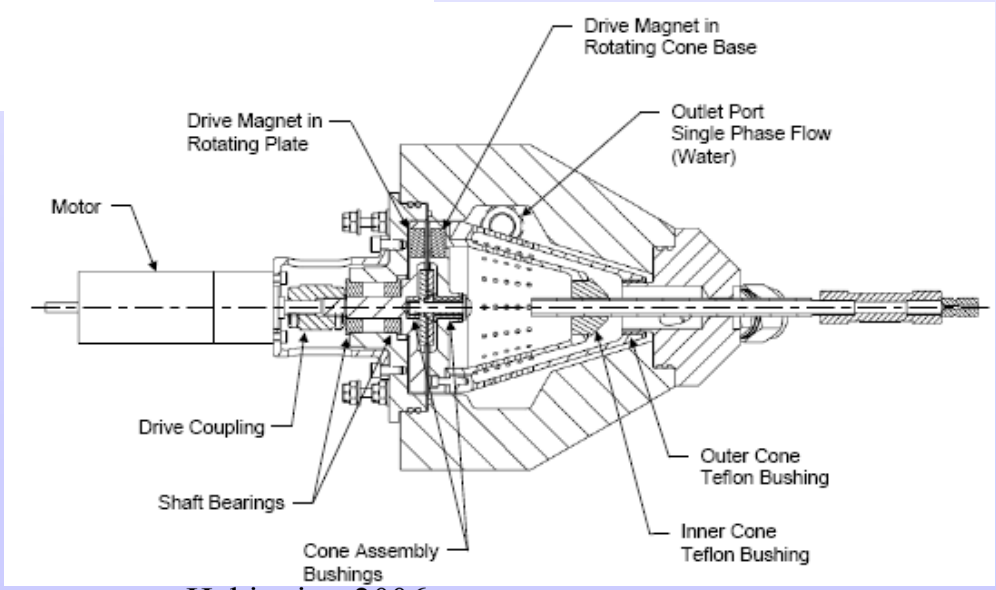
Original MOBI phase separator



Active Separator showing the formation of a cylindrical gas core (right) and its elimination (left)

Modified MOBI phase separator

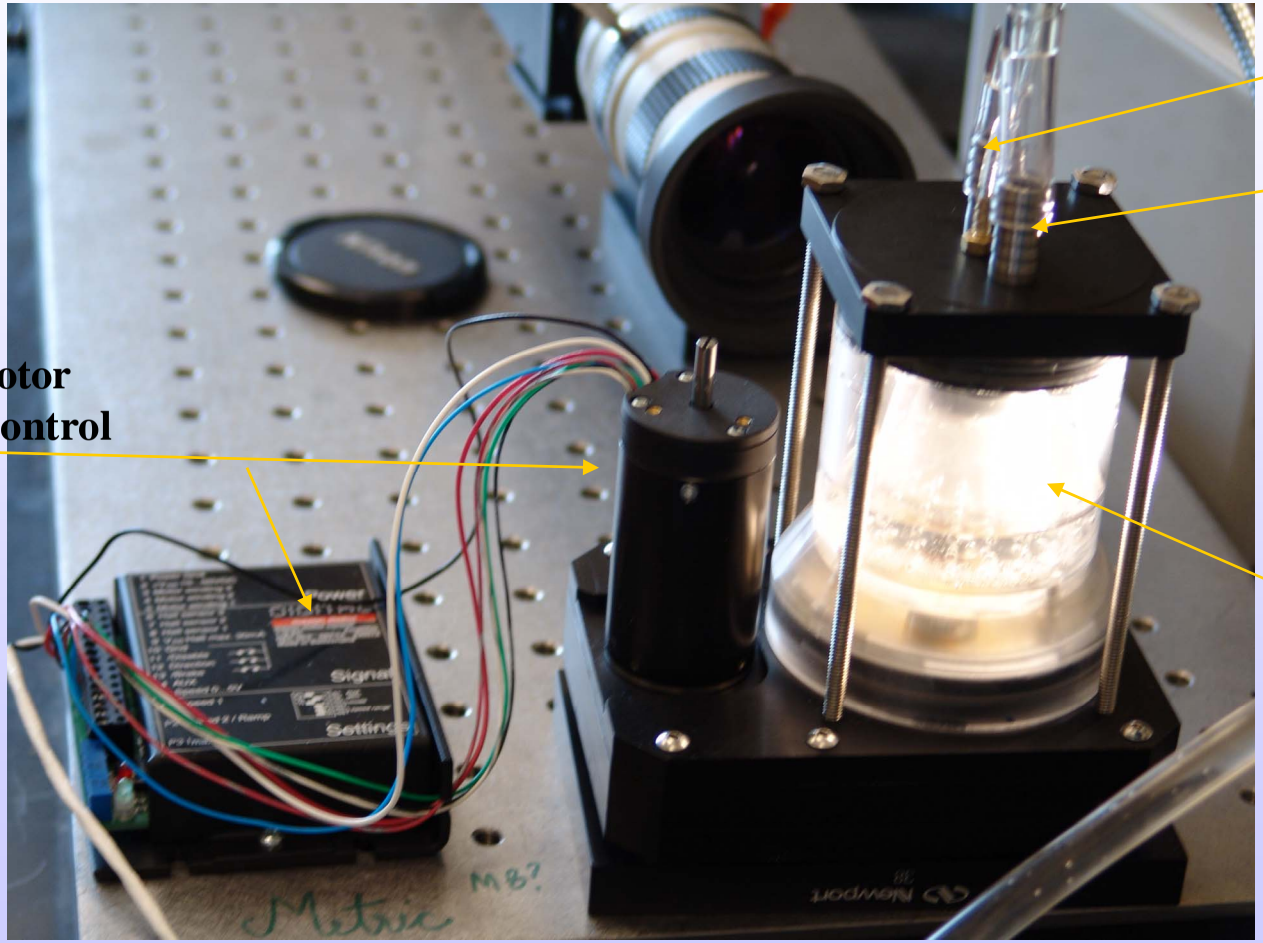




- Two phase flow is pump to centrifugal separator from inlet port
- Separator rotates from 800 -1600 rpm

Modified MOBI Phase Separator

Miniature MOBI Phase Separator



Experimental Set up (C9 rig)

- The flow loop was designed to test pumps and separators
- The flow loop consisted of an air and water delivery systems.
- **The air delivery system** is fed from a pressurized air bottle and is responsible for the delivery of air into the pumps being tested and for the inlet pressure of the liquid stream into the pumps.
- The water delivery system consists of
  - **an air-pressure-driven piston** which provides the pressure for the inlet stream,
  - **a separator** that provides the separation function of the two phase fluid that comes out of the pump,
  - **a recirculation pump** that is planned for use in the high g periods in the flight campaign.

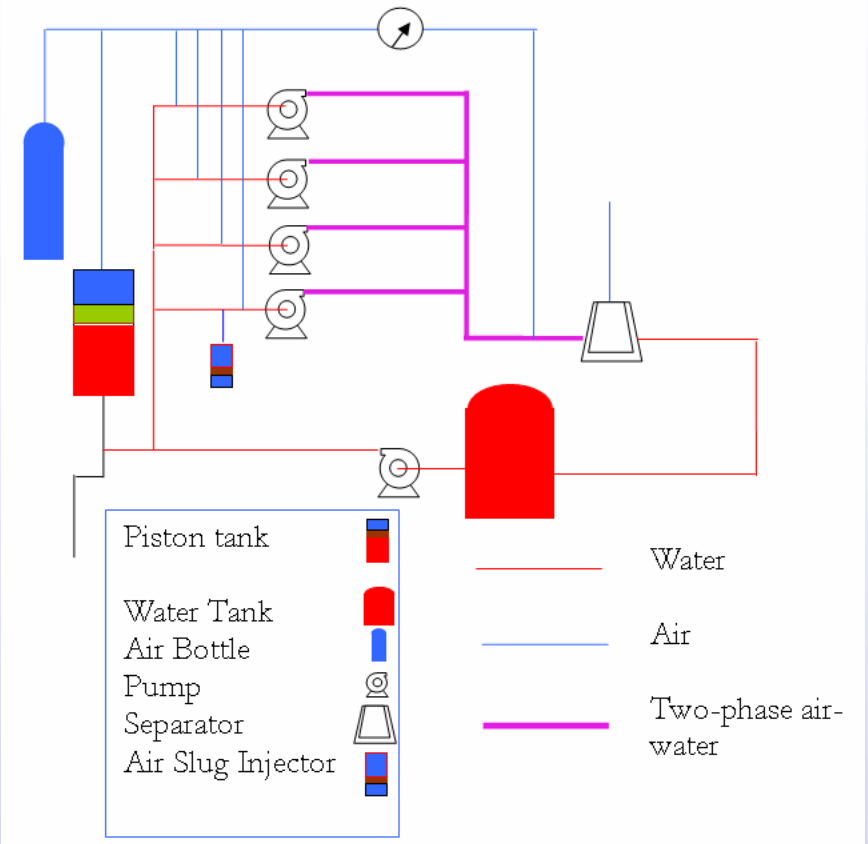


Fig 1.

Schematic of the two phase flow rig used to test the pumps and the gas liquid separators

- ***Experimental Set up (Continued)***
  - The flow loop was designed to accommodate the testing of four different pumps in one flight campaign.
  - The phase separator was on a mounted plate capable of being modified to allow other configurations of phase separators to be tested, however, only 1 phase separator could be tested at a time.
  - A high speed camera was used to take images of the phase separator in operation.
  - 2 cameras recorded images onto a mini DVcam of the water outlet and air outlet lines, respectively, to provide a quantitative assessment of how well the two phases were being separated.

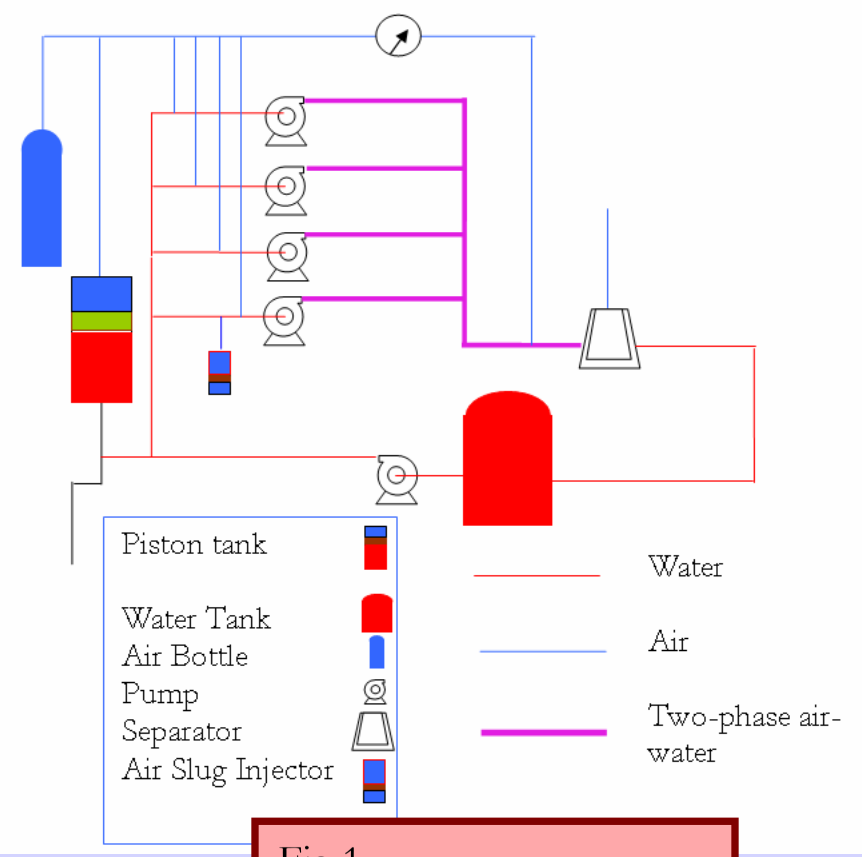
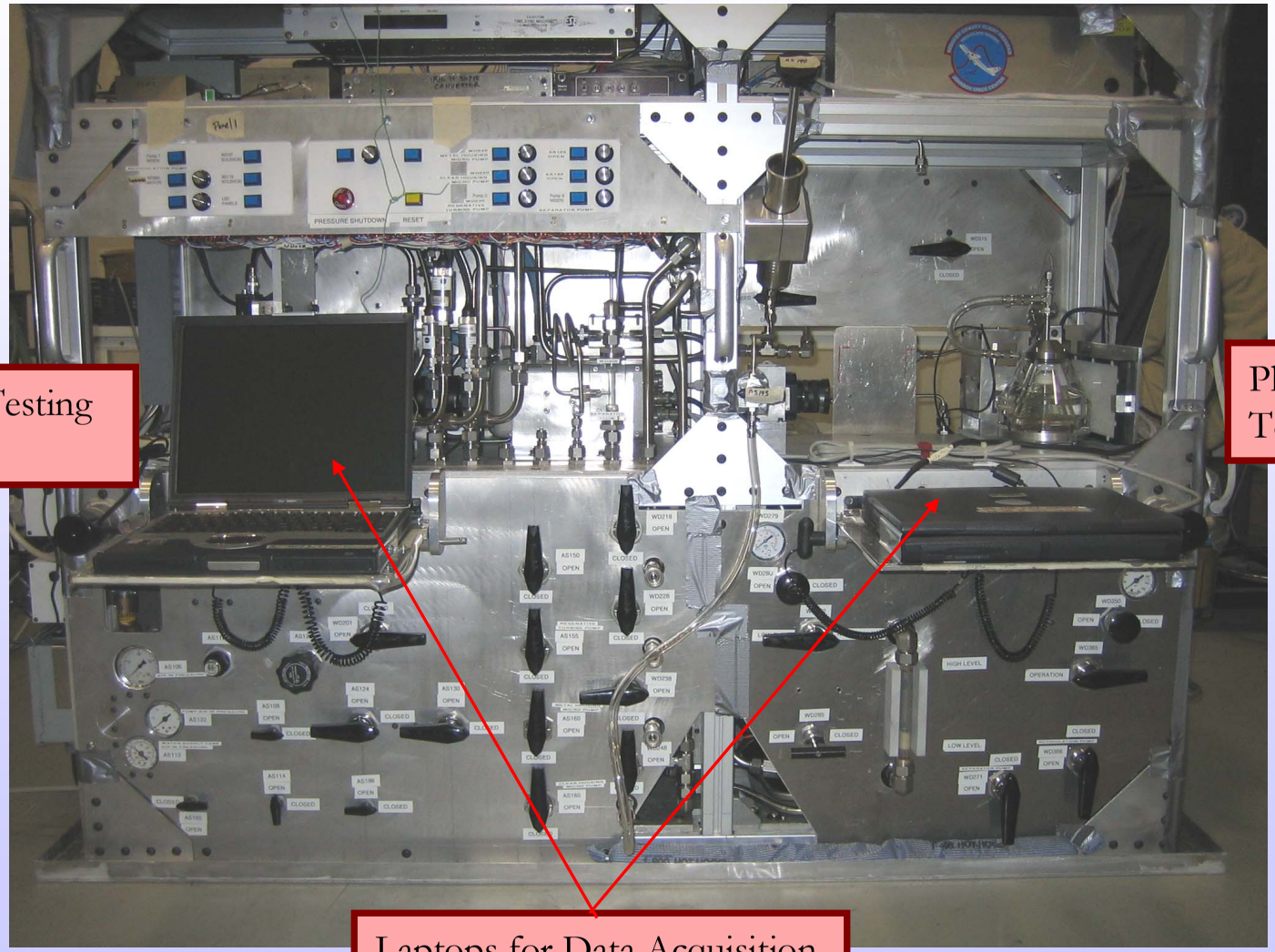


Fig 1.

Schematic of the two phase flow rig used to test the pumps and the gas liquid separators

C9 rig used for Pump and Phase Separator Testing



Phase Sep. Comparison Summary

Types	Specs.	Max water/air flow rates	Min water/air flow rates
Original MOBI phase sep.	•Cylindrical housing	4 *lpm* water 7.5 *lpm* air	60 *mlpm* water (electronics display limit) 5 *lpm* air
Modified MOBI phase sep.	•Conical housing	4 *lpm* water 100 *lpm* air	60 *mlpm* water (electronics display limit) 1 *lpm* air
Miniature MOBI phase sep.	•Miniature cylindrical housing	2 *lpm* water 2 *lpm* air	125 *mlpm* water and 1/4 *lpm* air

Design Comparison of Phase Separators

Original MOBI Separators

- Water entered from side at was redirected with 90º bends that increased the pressure loss across the separator.

Modified MOBI Separators

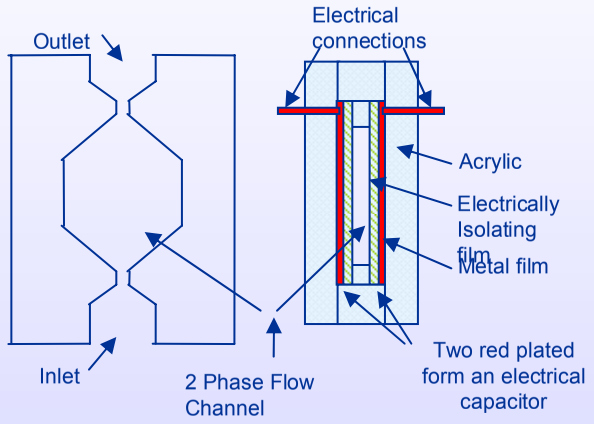
- Conical-shaped housing.
- Water outlet relocated from the top to the cone's side and is tangentially aligned.

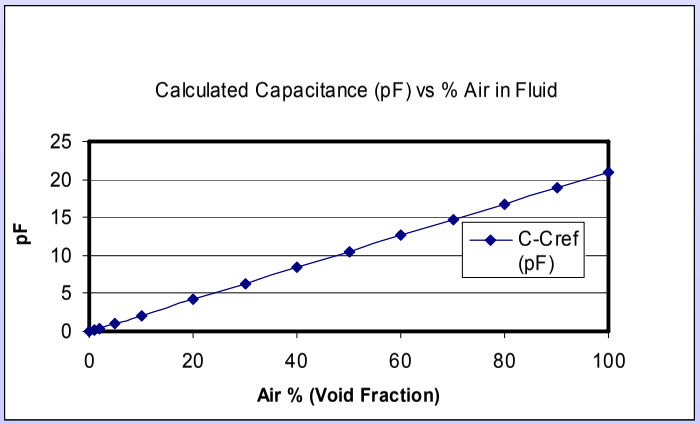
Miniature MOBI Separators

- 1/2 in. tube for two phases allows air to collect in tubing.
- No accurate measurement for lower air/water flow rates

Developing Non Contact Capacitive Type Void Fraction Sensor for Evaluation of Two Phase Separators

- To quantitatively measure the void fraction to assess the efficiency of two phase separation.
- We chose the plane parallel electrode design, providing a uniform electric filed across the flow regime. The 2 phase fluid flows through the rectangular cross section.
- Measurement system includes the capacitance to digital converter and the timer counter, D/A converter to obtain capacitance.
- Two identical sensors will be placed upstream and down stream in the separator to quantify the efficiency of the phase separator and also to compare with the high speed video image of the flow regime.





Conclusions/Future Work

- There are many applications within ALS that utilize multiphase flow technology that can benefit from the testing being done on phase separators.
- Continuation of the analysis of data and correlation of video to void fraction sensors, flow and pressure data is ongoing and will be presented in a future paper.
- Small design changes can have profound effects on overall air/water flow rates.
- Obtain low gravity data onboard C9 if such an opportunity presents itself.

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