The Packed Bed Reactor Experiment: an overview of hardware and science

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Life support systems in space depend on the ability to effectively recycle water from waste, air humidity and other water-producing systems. Subsystems and components critical to water treatment use packed-bed reactors for various stages of treatment. While design rules for gas-liquid flows through packed beds in normal gravity have been known for decades, they are lacking for other gravity environments. The Packed Bed Reactor Experiment (PBRE) focuses exclusively on the hydrodynamics of these flows, specifically, pressure drop, holdup and flow regime map correlations. Flow regime (implying phase distribution) and holdup correlations are a prerequisite to developing mass transfer correlations needed to model the reactor.

The packed bed consists of a cylindrical test section 60 cm in length and 5 cm in diameter, filled with 3mm-diameter spherical beads. To examine the effect of wettability, two test sections will be tested, one with glass and the other with Teflon beads. The fluids are ISS-nitrogen and water. Water and gas exiting the test section flow into a centrifugal vortex phase separator. The water is recycled into the test section, while the gas is vented.

Science Diagnostics: 5 absolute pressure transducers and two high-speed video cameras (up to 170 fps) along the test section.

Video: Two high-speed video cameras (AVT GX1050) are trained at two 10-cm segments along the test section length. One segment is located at the column inlet and the other is 3/4 of the total column length downstream of the inlet. The field of view is 6X from 74.4 mm to 12.5 mm in the axial direction. The frame rate is variable with a maximum of 170 fps. The camera lenses are parfocal, so they maintain focus across zoom magnifications. Strobe lights are also used for illumination, with the camera shutter providing stopping action.
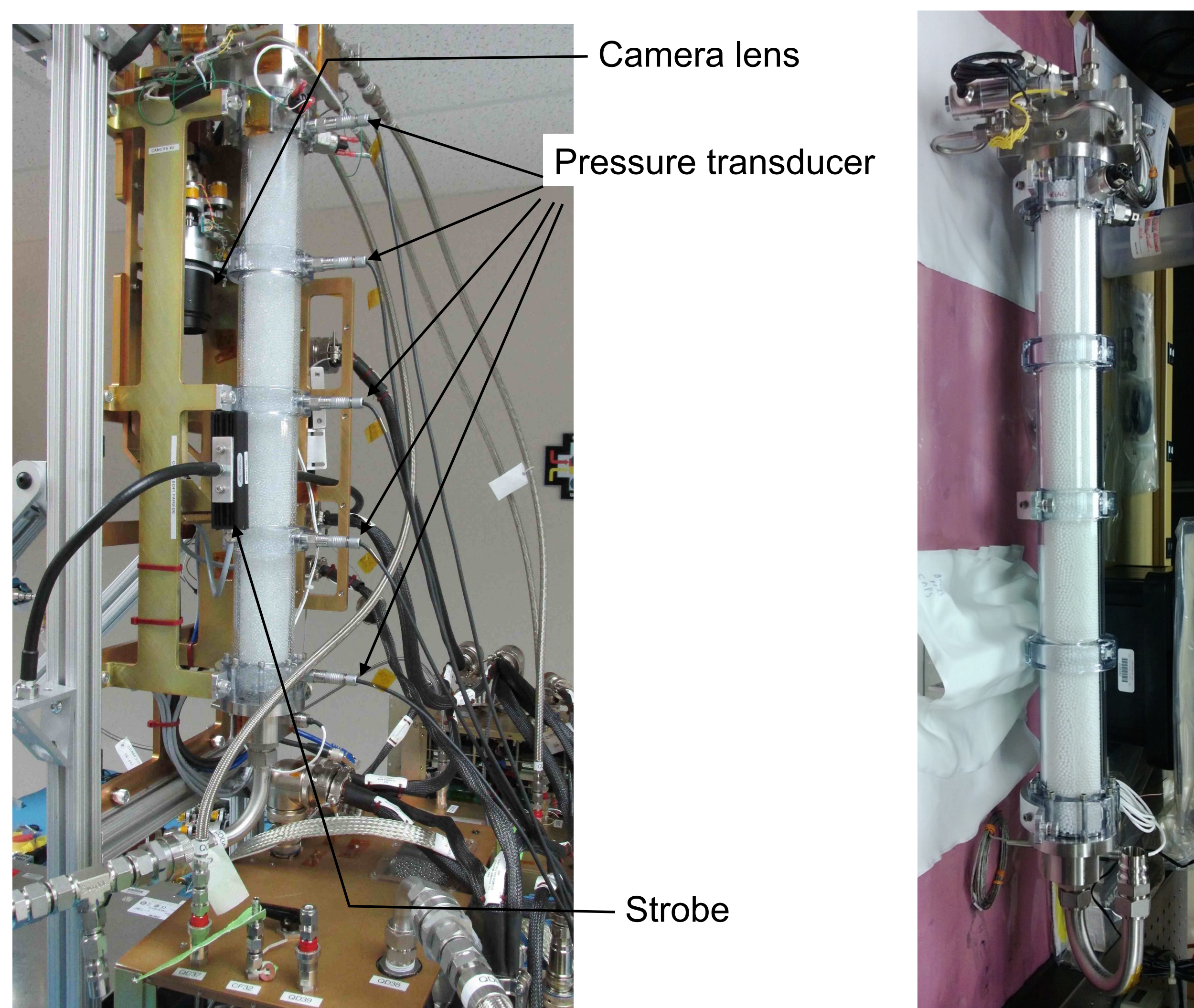

Fig. 1: Flow Diagram of the PBRE flight hardware

Fig. 2: Left: Test section with glass beads showing key components (Engineering Model). Note the 5 pressure transducers; and one camera trained to the third sector of the column. The PBRE fits in the ISS Microgravity Science Glovebox. **Right:** Test section packed with Teflon beads.

Gas flow rates must be measured to 1% of actual flow rate for G>0.01 kg/hr; and to 2% of actual flow rate for G<0.01 kg/hr. Liquid flow rates must be measured to 1% of actual flow rate. (See Table 1.)
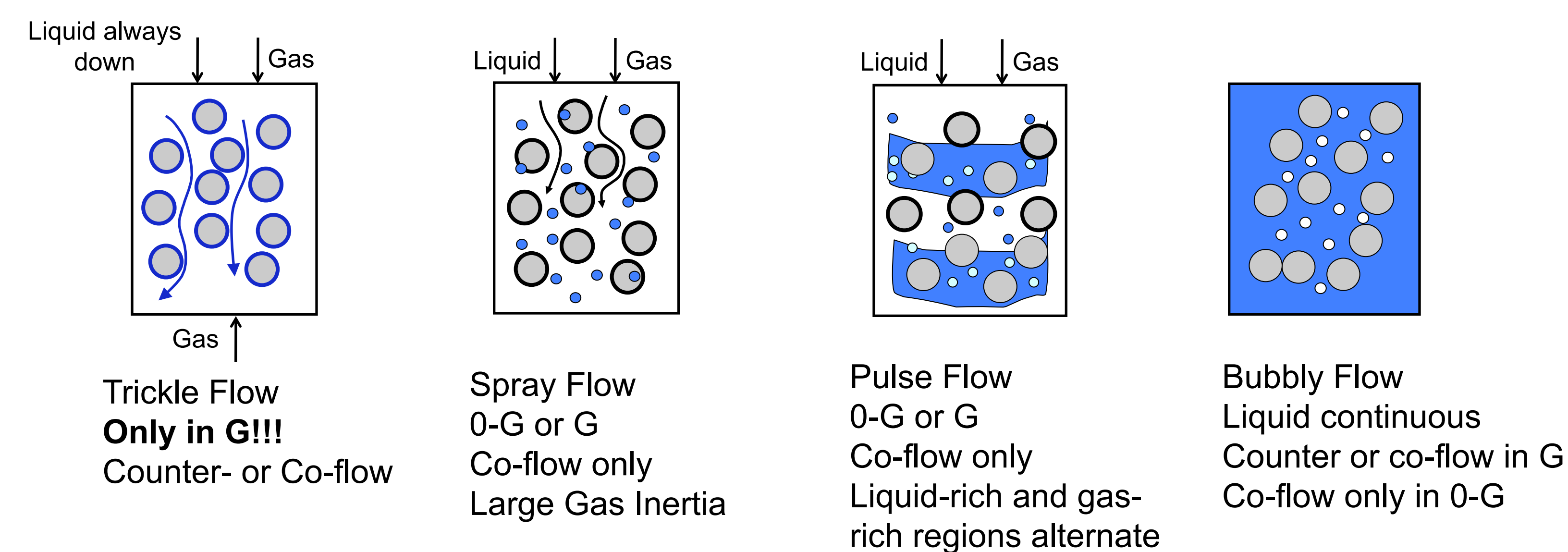
Flow Regimes

Fig. 3: Flow regimes in normal and low gravity.

Trickle flow: liquid flow rate is low enough that liquid never floods the column. Trickle flow can not develop in zero-gravity as it needs gravity for liquid to flow down. All other regimes can arise in any gravity level.

Bubbly flow: liquid is continuous and gas is dispersed. Co-flow only in zero-gravity but either co-flow or counter-flow (where liquid flows down and gas rises by buoyancy for large enough bubbles) can develop in normal gravity.

Pulse flow: most efficient for mass/heat transport in multiphase flows. For fixed liquid flow rate, bubbly-to-pulse transition occurs as gas flow rate is increased.

Spray flow: only with high gas inertia. Not relevant in microgravity applications.

Test matrix philosophy: 1) *Steady state:* Identify flow regime boundaries in steady state. Increase gas flow rate for each fixed liquid flow rate. 2) *Transients:* increase, then decrease gas flow rate for each fixed liquid flow rate. Look for hysteresis in pressure drop and flow regime boundaries.
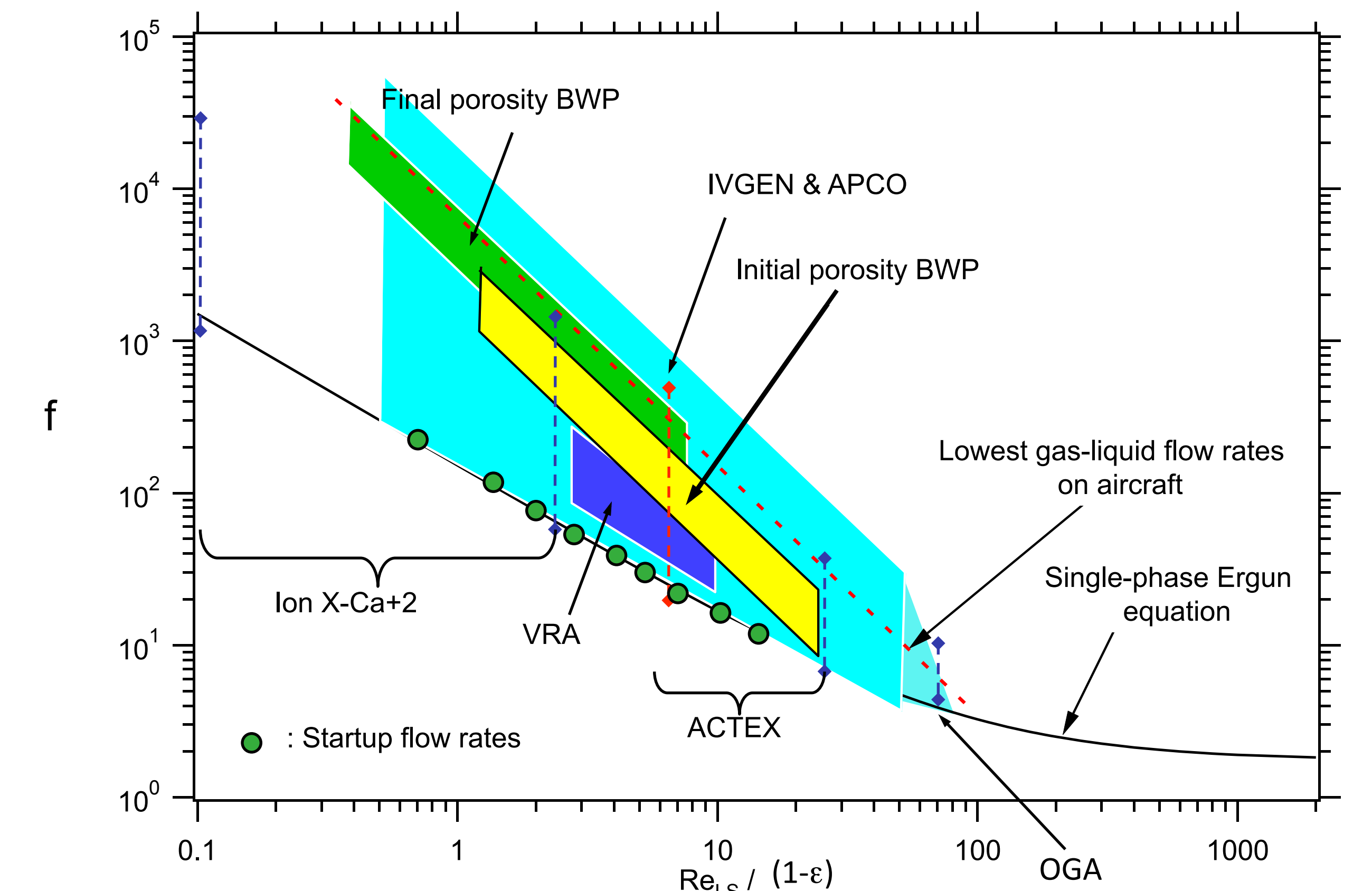

Fig. 4: PBRE Operation Range: this plot of friction factor (f) vs. liquid Reynolds number (Re_L) shows the relevant regions of operation for several water purification concepts. The area in turquoise is the PBRE test range. Conditions below red-dashed line cannot be handled in the low-gravity aircraft due to limited 0-g time on aircraft. All purification concepts fall below the low-g aircraft range.
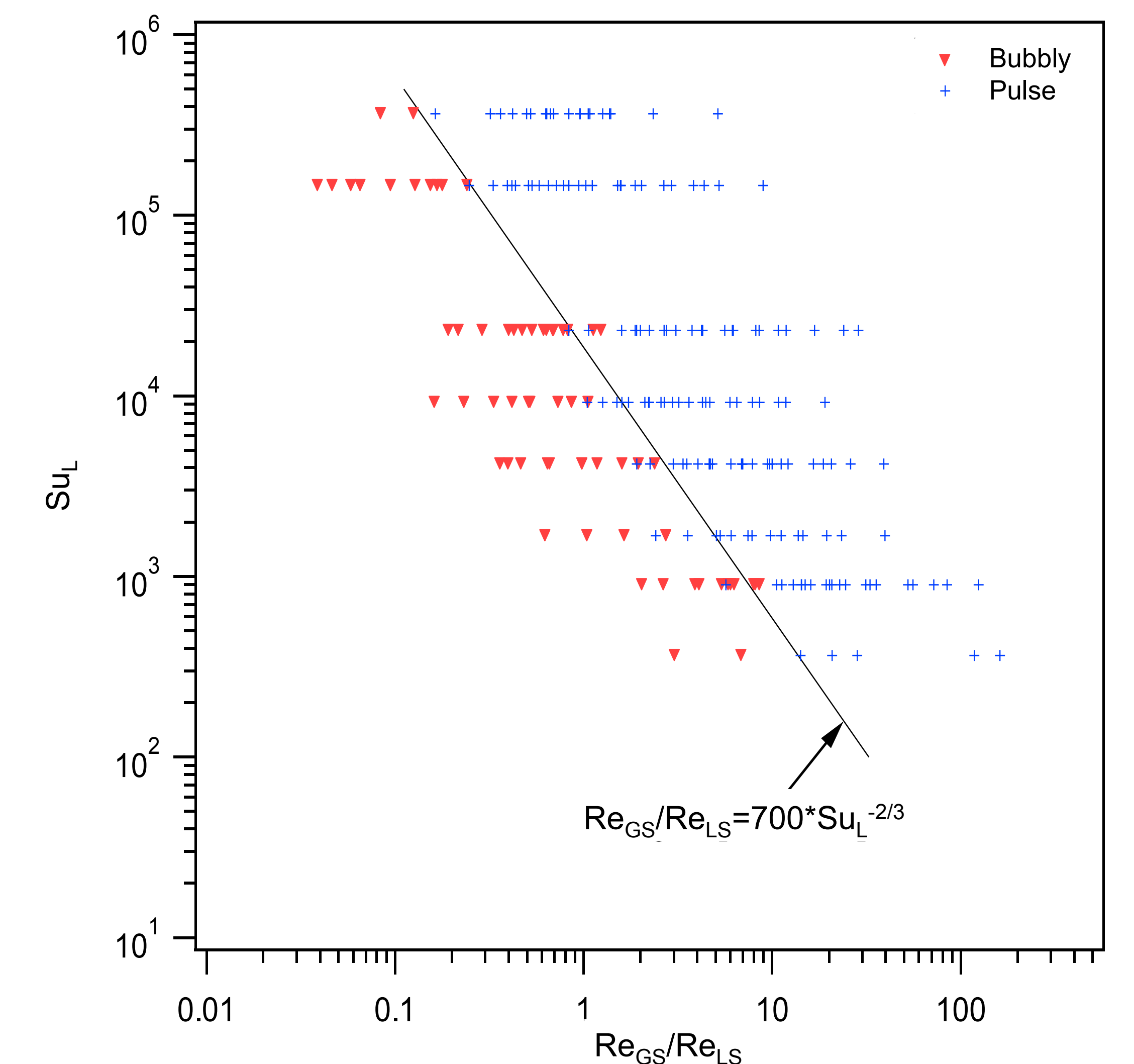

Fig. 5: Low-gravity bubbly-to-pulse flow regime transition: Aircraft data showing a clear boundary between bubbly and pulse flows. Vertical axis: Suratman number ($Su=d_p\sigma\rho_L/\mu_L^2$); horizontal axis: gas over liquid Reynolds numbers. In normal gravity and for a given liquid flow rate, this transition occurs at higher gas flow rates.

Fluid	Min. flow rate	Max. flow rate	Range	Max. incr.	Control
Gas (kg/hr)	0	3	G<0.01 0.01<G<0.1 G>0.1	0.0005 0.01 0.1	±0.0002 ±0.005 ±0.05
Liquid (l/hr)	0	150	L<20 L>20	1 5	±0.5 ±1

Table 1: Flow rate requirements capabilities

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