Gas-Liquid Two-Phase Flows Through Packed Bed Reactors in Microgravity

The simultaneous flow of gas and liquid through a fixed bed of particles occurs in many unit operations of interest to the designers of space-based as well as terrestrial equipment. Examples include separation columns, gas-liquid reactors, humidification, drying, extraction, and leaching. These operations are critical to a wide variety of industries such as petroleum, pharmaceutical, mining, biological, and chemical. NASA recognizes that similar operations will need to be performed in space and on planetary bodies such as Mars if we are to achieve our goals of human exploration and the development of space. The goal of this research is to understand how to apply our current understanding of two-phase fluid flow through fixed-bed reactors to zero- or partial-gravity environments.

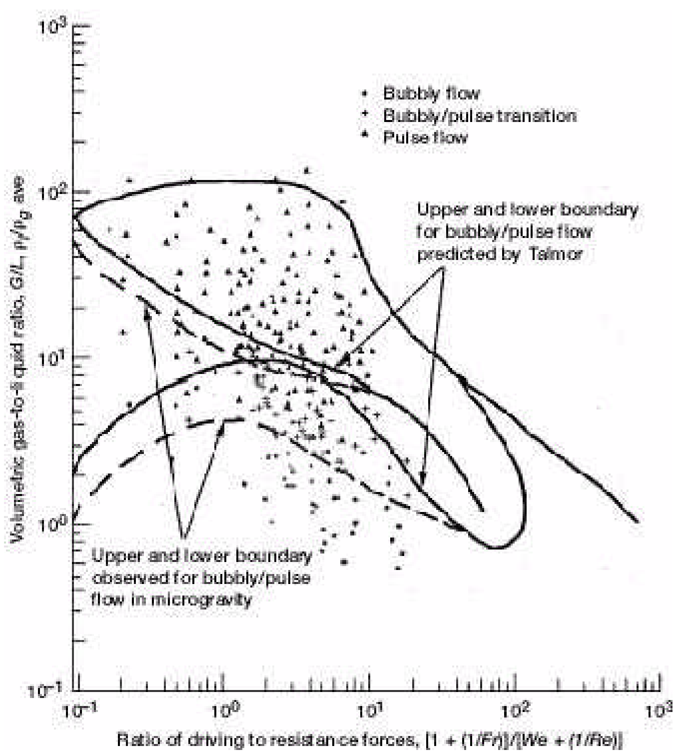
Previous experiments by NASA have shown that reactors designed to work on Earth do not necessarily function in a similar manner in space. Two experiments, the Water Processor Assembly and the Volatile Removal Assembly have encountered difficulties in predicting and controlling the distribution of the phases (a crucial element in the operation of this type of reactor) as well as the overall pressure drop.

To address this problem, the NASA Glenn Research Center has begun an in-house study on the effects of a microgravity environment on gas-liquid flow through a packed bed reactor. The initial study compares an established flow regime map developed by E. Talmor in 1977 (ref. 1) to similar flow conditions under microgravity. The Talmor map uses dimensionless quantities that account for the effects of gravity. In theory, by adjusting the gravity term, this map should also be applicable to reduced gravity.

Researchers Eric Dao (University of Houston) and Brian Motil (Glenn) work on a packed bed reactor experiment on NASA's KC-135 aircraft.

Four different flow patterns or regimes exist for nonfoaming systems in normal-gravity flows. Two of the flow regimes can be classified as "gas continuous" because the gas phase occupies most of the void space within the column. At both low gas and low liquid flow rates, trickle or channeled flow is observed. In this important flow regime, the liquid phase trickles down the packing, driven mainly by the draining force of gravity. The liquid forms a laminar film that frequently does not wet the entire packing surface, and interaction between the phases is relatively low. As the gas flow is increased, the liquid film becomes turbulent and eventually the gas flow is strong enough to suspend droplets of liquid. This flow regime is generally called spray or mist flow. At higher liquid flow rates and relatively low gas flow, the continuous phase is now liquid and the gas phase is uniformly dispersed in small bubbles throughout the column. This regime is called bubbly flow. Finally, an interesting flow regime exists for a specific range of gas and liquid flow rates called the pulse flow regime. This flow regime can be observed as the liquid flow is increased beyond trickle flow until pulses (traveling waves) of liquid can be observed. The waves quickly grow until they span the entire cross section of the column.

The experimental apparatus used to compare flow regimes in microgravity was flown on NASA's KC-135 aircraft (photograph). The results are shown in the graph. The black lines indicate Talmor's predictions based on normal gravity testing of concurrent downflow conditions. The data shown are from the microgravity testing and are used to generate the new curves (dashed lines). This series of tests indicate a significant shift in the pulse and bubbly flow regimes. The onset of pulse flow is shown to occur at a much lower gas-to-liquid ratio than is predicted. Research is ongoing with plans to develop a more comprehensive model.



Flow map for two-phase downflow through packed beds in microgravity.

Reference

1. Talmor, E.: Two-Phase Downflow Through Catalyst Beds. AIChE J., vol. 23, no. 6, 1977, pp. 868-878.

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