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"CIRCULATION IN GAS-SLURRY COLUMN REACTORS"
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SUMMARY

Circulation in bubble columns detracts from their performance in that gas is carried on average more rapidly through the column, and the residence time distribution of the gas in the column is widened. Both of these factors influence mass-transfer operations in bubble columns. Although circulation has been modeled with moderate accuracy, there is still a dearth of good data and reliable models for bubble columns. To remedy this omission, circulation prediction and measurement has been undertaken using probes, one-dimensional models, laser Doppler velocimetry, and numerical modeling.

Firstly, local void fraction was measured using resistance probes and a newly developed approach to determining air/water threshold voltage for the probe. A tall column of eight inch diameter was constructed of Plexiglas and the distributor plate was manufactured to distribute air evenly through the base of the column. Data were gathered throughout the volume at three different gas throughputs. Void distributions were quite flat near the distributor, becoming more parabolic higher in the column. Orthogonal traverses of the column with the probes verified that the circulation was symmetric. Bubble velocities proved difficult to measure using twin probes with cross-correlation because of radial bubble movement. However, data have been obtained for several central positions in the column at different flowrates of air. Measured bubble velocities agreed acceptably with predictions of a one-dimensional mode., and this model has also been extended to include a drift-flux approach.

Secondly, a series of three-dimensional mean and RMS bubble and liquid velocity measurements have been obtained for a turbulent flow in a laboratory model of a bubble column. These measurements have been made using a

three-component laser Doppler velocimeter (LDV), to determine velocity distributions non-intrusively. A hexagonal bubble column cross-section was selected to allow relatively easy optical penetration by the LDV into the column. Bubble column turbulent liquid circulation for these experiments was due to injection of air into water from a single vertically oriented jet on the column centerline.

Measured distributions of mean vertical and radial liquid and bubble velocities indicated a toroidal recirculating liquid mean flow which was driven by the air jet. Mean velocity was upwards near the column centerline, radially outwards near the free surface, downwards near the column wall, and inwards in the bottom of the column. Laser light sheet flow visualization was qualitatively consistent with the quantitative LDV data. Mean circumferential (swirl) velocity was essentially zero. Measured RMS velocity fluctuations were the same order of magnitude as measured mean velocities for both phases. Thus, turbulence intensities were on the order of 100% throughout the column. The turbulence field was non-isotropic, in that the radial RMS velocity was consistently larger than either the vertical or circumferential RMS velocity. This non-intrusive set of three-component mean and turbulent liquid and bubble velocity data in a laboratory bubble column is unique and previously unavailable in the literature.

Thirdly, the gas-liquid flow inside a vertically situated circular, isothermal column reactor has been simulated numerically. The gas-liquid flow is assumed to be in the bubbly flow regime which is characterized by a suspension of discrete air bubbles in a continuous liquid phase such as a glycerol-water mixture. The mathematical formulation is based on the conservation of mass and momentum principle for the liquid phase. The gas

velocity distribution is calculated via an empirically prescribed slip velocity as a function of void fraction. The interface viscous drag forces are prescribed empirically. A profile shape is assumed for the void ratio distribution and the magnitude of it is calculated as part of the solution. The influence of various profile shapes is investigated. Results with the void ratio distribution calculated from the conservation of mass equation for the gas phase are also presented. The mathematical model has been implemented by modifying a readily available computer code for single phase Newtonian fluid flows. The numerical discretization is based on a finite volume approach.

The numerical predictions show a reasonably good agreement with measurements. The circulation pattern seems not to be so sensitive to the actual shape of the void fraction profiles, but the inlet distribution of it is important.

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SECTION 1

INTRODUCTION

In a Fischer-Tropsch synthesis hydrogen and carbon monoxide are combined in the presence of a catalyst to produce hydrocarbons. The input gases can be generated using fluid bed gasifiers. Synthesis can be carried out in a bubble column where the gases are passed through a slurry of catalyst and high molecular weight oils produced by the synthesis itself (Stern et al., 1985). The bubble column reactor offers several advantages over conventional fixed bed reactors: lower hydrogen to monoxide ratios can be tolerated and hot-spots are controlled in the bed so that catalyst deactivation is reduced. Although gas may be introduced evenly through a distributor plate into the slurry, circulation patterns can develop in bubble column systems. The most common of these patterns involves a high concentration of gas bubbles in the column center and less near the wall. In consequence a gas-slurry mixture rises up the column center and slurry flows back down near the column wall. The circulation is known as "gulfstreaming" (Freedman and Davidson, 1969). At the bottom and top of the column there are strong radial velocity components to complete the circulation pattern.

Gulfstreaming reduces the efficiency of many unit operations by "shortcircuiting" the air bubbles, thus reducing their residence time and holdup in the vessel. To maintain an acceptable residence time of bubbles in the system, bubble columns must often be designed far taller than if there were no gulfstreaming. On the other hand, the presence of large circulation patterns leads to the formation of turbulent eddies in the column, promoting mixing and mass and heat transfer. Residence time distribution is also altered by the presence of circulation, an important consideration in predicting conversions (Chang and Smith, 1983). Therefore the degree of circulation in the column must be predicted if accurate column designs are needed. More complex circulation patterns can also be observed, with cells side-by-side (in large diameters - see Otero et al, 1985) or above one another (reported in fluidized beds by Lin et al., 1985). A single cell reverse pattern, with slurry rising at the walls and flowing back at the center is also possible. State-of-the-art models for circulation are still not sufficient for accurate column design. This research has attacked the problem of circulation prediction and measurement through experimental work using probes, one dimensional modeling, laser doppler velocimetry measurements, and numerical modeling. These three areas are addressed in the following sections.