Digital Image Analysis Study of Bubbling, Solids Mixing and Segregation in Fluidized Beds.

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Thesis submitted for the degree of

Doctor of Philosophy

in

The University of Adelaide

(Faculty of Engineering)

(August 1992)

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SUMMARY

In the design of bubbling fluidized-bed reactors, a good understanding of the bubbling phenomena is required. It has been well recognized that the bubble hydrodynamics influence the solids mixing and segregation in the fluidized bed. Although the mechanisms for solids mixing and segregation have been reasonably well studied and characterized, detailed modelling and experimental verification of the behaviour of the fluidized bed still remains a challenge. The key limitation lies in the scarcity of experimental data on simultaneous characterization of bubble flow and solids mixing.

In this study, novel techniques utilising digital image analysis have been developed for quantitative measurement of bubbling phenomenon with the presence of both bubble and dense phases in a two-dimensional fluidized bed.

The development of the experimental techniques for the measurement of the gas bubble parameters, concentration of coloured solids tracer in homogeneous and binary particle systems will be described. In addition, a unique experimental method for the tracking of the larger and lighter particles circulating in the fluidized bed will also be presented. The measurement and analysis methods are objective and fully automated, hence, eliminating all subjective determination and tedious manual effort on data acquisition and analysis.

In the study of the bubble hydrodynamics, distributions of bubble size, shape, velocity in a two-dimensional bed have been measured for various bed heights, particle sizes and operating conditions. In addition, pierced length and several size measures of bubbles intercepted at an 'imaginary' probe in a thin two-dimensional fluidized bed were measured. Prediction of bubble size from measurements on bubble pierced lengths

using the geometrical probability approach and bubble shape assumptions has been assessed and discussed. Measurement of the bubble size/shape, velocity and the angle of rise also enable experimental assessment of the limitations of dual-tipped probes commonly used in three-dimensional beds.

In the solids mixing study, the course of mixing of uniform solids in two-dimensional bubbling fluidized beds has been followed. In this investigation, experimental data have been obtained on the axial mixing of uniform solids. Oscillations in the concentration response, resulting from the gross circulation of the solids, have been observed experimentally. These oscillations become increasingly more prominent as the bed particle size increases. These measurements have been used to evaluate the three-phase counter-current back-mixing model. The bubble parameters required for the model were obtained from independent experiments conducted as a part of this investigation; the exchange coefficient, however, was found by parameter estimation using the solids mixing data. With this choice of parameters, the counter-current flow model has been found to predict the experimental trends reasonably well. The estimated values for the exchange coefficient do not compare favourably with the predictions of the models available in the literature. These models predict that the wake exchange coefficient should increase with increase in the minimum fluidization velocity of the bed particles. Our results, on the other hand, show that the wake exchange coefficient increases with U_O/U_{mf} for $U_O/U_{mf} < 3$ and the values, in this region, are independent of the particle size.

The technique used for the study of mixing of uniform particles was extended to the study of segregation phenomenon resulting from size or density differences. Unsteady material balance equations from the Gilibaro-Rowe (1974) and Yoshida (1980) models for segregating fluidized beds were solved numerically. The possibility of the formation of a defluidized layer at the bottom of the bed was taken into account.

Comparison of model predictions with data indicated that though these models did reflect some features of the experiment, the influence of the superficial velocity on the temporal variation of the concentration at any specific height within the bed was not predicted. In fact, a trend completely opposite to that predicted was observed experimentally. If these models are to be used, then the segregation rate parameter must have a dependence on superficial velocity substantially different to that currently available in the literature. Further work in this direction is recommended. The influence of jetsam concentration was not explored in this experimental study; such measurements are recommended as well.

Some preliminary empirical relations were established for the movement of the defluidized layer with time. In particular, a promising new indicator for segregation propensity was proposed from analogy with vapour-liquid equilibrium data representation methods. Additional data are necessary before further generalization can be attempted.

Finally, a specific aspect of bubbling beds which has important significance, especially in the area of coal combustion, has been investigated. In bubbling fluidized bed combustion, large coal particles - comprising about 1% of the total bed inventory - are fluidized along with smaller sulphur-sorbent particles. The density of the coal particles is less than that of the bed particles. This combination of the concentration, size and density for coal and bed particles results in the setting up of circulation pattern for the coal particles. The motion of a larger and lighter particle circulating in a fluidized bed has been determined. The larger particle was found to move downward near the wall region and travel up in the central core of the fluidized bed in a jerky manner. The characteristic particle velocities in both regions have been measured. The present experimental technique enables, for the first time, the determination of the phase residence probability of the particles associating with the dense phase. A simple model has been proposed for the prediction of this quantity as a function of excess gas velocity.