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Time-Dependent Behavior of Large-Particle Fluidized-Bed Hydrodynamics

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1. Summary

Significant progress has been made in researching the time-dependent behavior of fluidized-bed hydrodynamics. The Ph.D. thesis of Alan Weimer documents theoretical advances based on a mixture-flux concept and includes experimental evaluation. The work of Gyure, which is in progress, has successfully brought the fluidization state under feedback control.

2. The Fluidization Research Program--Background

In 1977 we embarked on research in a new area: development of advanced control systems for large-particle fluidized-bed processes such as coal gasification and combustion. A stumbling block appeared immediately: the lack of adequate mathematical models of the time-dependent behavior of fluidized beds. Such models are prerequisites to the application of modern control theory. Even steady-state models of these processes seemed naive.

Through the Master's research of Weimer, many recent advances in fluidization were integrated in a comprehensive steady-state mathematical model of a low-pressure, steam-oxygen gasifier. Aspects of this work were presented at the AIChE Annual Meeting in San Francisco in 1979, have since appeared in Chemical Engineering Science, and will appear in an upcoming AIChE Symposium Series volume.

A first attempt at modeling time-dependent behavior in a fluidized-bed coal combustor was made via the Master's research of Payne. The approach used moments of the particle-size distributions of coal, dolomite and ash plus moments of the conversion distribution of dolomite, the sulfur acceptor. Although mathematically sound, the model was difficult to solve numerically, and this led us to search for a new technique for modeling the dynamics of the distributions. As part of his doctoral dissertation, Weimer developed

a successful approach based on orthogonal collocation of the distribution curve, and this has been applied to char gasification, first for an isothermal model, than a nonisothermal one. These results appeared in two articles in Powder Technology. Future research in this area will include on-line distribution estimation.

As part of a subcontract of the Department of Energy via Rockwell International, we developed a control system for a fluidized-bed process, conversion of plutonium and uranium nitrates to oxides. Owing to the high density of the heavy metal particles in the bed, there is a narrow margin above minimum fluidizing gas velocity before the bed begins to slug. This characteristic yields a difficult control problem. Robertson, in his M.S. research, developed a method for on-line, closed-loop control of the fluidized state which utilized variance of the bed's differential pressure signal as the measured variable and gas flow as the manipulated variable. This work has recently been extended by Gyure (see section 3.2).

As our dynamic modeling efforts progressed, a subdivision into three topics occurred:

1. hydrodynamics: time-dependent behavior of emulsion and bubble phases
2. particle size and conversion distributions
3. material and energy balances for the emulsion gas and bubble phases

The first topic has been addressed in the doctoral research of Weimer (see section 3.1). An experimental apparatus was constructed and used to test the theoretical predictions for hydrodynamics. General Electric and Du Pont supplied the funds necessary to build this fluidized-bed unit. Topic 2 has

been discussed above. Weimer also developed a theoretical framework for topic 3 as part of his doctoral dissertation.

As implied above, the long-range goal of this program is to use our results in dynamic modeling for the development of advanced control systems for fluidization processes. Up to the present, our efforts have been directed primarily toward the modeling phase.

3. Research Activity from 9/1/80 through 2/28/81

3.1 Time-Dependent Behavior of Hydrodynamics

This is the primary research topic supported by DOE grant DE-FG22-80PC30245. Doctoral student Alan W. Weimer was supported under this grant from 9/1/80 through 12/31/80 and his Ph.D. thesis documents significant progress in this area as described by the following points:

- a) A novel description of the time-dependent behavior of macroscopic fluidization hydrodynamic properties has been developed based on a mixture-flux concept.
- b) Computer simulations using this model have been carried out to compare steady-state predictions with experimental results of other investigators.
- c) Experimental testing of the dynamic version of this model has been carried out in our laboratory including on-line estimation of fluidization hydrodynamic parameters.

The first result of this work which we will highlight by presentation at the AIChE Annual Meeting in New Orleans later this year is the steady-state bubble velocity equation resulting from this model. This equation represents a significant improvement over others available. It accounts for a number of factors which contribute to deviations of actual bubble velocity from

prediction of the Davidson and Harrison two-phase-theory equation. These factors include:

- a) interference between adjacent bubbles
- b) non-uniform radial bubble distribution
- c) reduction in bubble flow below that predicted by excess flow above minimum fluidization.

Our equation has a theoretical basis, yet yields, with appropriate simplifications, the Davidson and Harrison equation which is partially empirical in origin.

3.2 Feedback Control of the Fluidized State

An extension of the previous work of Robertson is in progress. This research is being carried out by Dale C. Gyure in his M.S. program. We are seeking a practical characterization of the fluidized hydrodynamic state which can be used in a feedback control system.

Gyure has shown from experimental results that parameters of a time series model describing bed pressure drop vary monotonically with the gas flow rate. He has also been able to control model parameter values using a simple integral-only feedback law to manipulate gas flow. Although the time series model is empirical, we hope to relate it to fundamental bed hydrodynamic parameters using the results of Weimer's work.

4. Projected Activity

In the period 3/1/81 through 8/31/81, we project the following research activity:

- a) Gyure will complete his M.S. work including application of a self-tuning regulator to fluidization state control.

- b) The mixture-flux model developed by Weimer will be studied intensively with attention toward prediction of distribution coefficient, coalescence frequency factors, and gas flow division.
- c) A new M.S. student, Michael D. Michonski, will simulate particle size distribution dynamics using 3-D images on computer graphics. He will also complete his orientation in fluidization research.

5. Publications

1. Weimer, Alan W., "An Experimentally-Verified, Mixture-Flux Model for Time-Dependent Behavior of Bubbling Fluidized Bed Hydrodynamics: Char Gasification Dynamics," Ph.D. Thesis, University of Colorado, December, 1980.