Particle transport in fluidized beds
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Chapter 1

Introduction and Guide to the Thesis

1.1 Background

The operation of the world’s first large-scale, commercial, fluidized bed reactor was started by Fritz Winkler for the gasification of powdered coal in 1926. Since then fluidized beds have been developed vigorously for different physical and chemical operations, such as transportation systems and chemical reaction processes. As the demand for petrol rose in the Second World War, research in catalytic cracking of heavy oils was desperately needed. At this time, a group of researchers at the Massachusetts Institute of Technology had proposed and confirmed experimentally that a completely pneumatic circuit consisting of fluidized beds and transport lines could be operated stably for a satisfactory catalytic cracking process (Kunii and Levenspiel, 1991). Esso engineers concentrated on this idea and built a large-scale pilot plant of an up-flow cracking unit (Geldart, 1986). The Fluid Catalytic Cracking (FCC) process was then on track.

The world’s first Fluid Catalyst Cracking unit was constructed at the Baton Rouge refinery in Louisiana in 1942, and this type of reactor remains a fundamental and essential reactor in the field of process engineering. Currently a FCC unit is a standard component in the production of gasoline and other fuels from heavy oil components, and is at the heart of practically every oil refinery in the world. The FCC unit is an example application of fluidized bed reactors that have had a major impact on industrial processes. In fact, fluidized bed reactors are already utilized for a wide range of applications where contact between gas and particulate solids is required together with good solids mixing and heat transfer, for example mixing of powders, coating, heat exchange, drying and classifying materials.

The complexity of solid movement within the beds depends on a number of parameters such as the geometry of the bed and physical properties of particles. A small difference in those parameters can cause a severe change in terms of the efficiency of fluidized bed reactors. To make sure that a fluidized bed reactor is at optimum efficiency, normally either a small or large pilot model is made and investigated to test the proposed fluidized bed. Even though the experiments and
pilot model were tested before building a real unit, problems have often occurred when attempting to construct and operate the large-scale unit.

Since the availability of computers has significantly increased, the use of mathematical models to predict the performance and efficiency of an existing or newly designed fluidized bed also has increased. A number of mathematical models have been proposed for fluidized beds. Most of the models used in chemical engineering and also in fluidization have been deterministic differential equation models based on conservation equations. Stochastic models have been much less popular in the past, though they have been successfully used to describe flow systems and to compute their residence time distributions.

In this thesis the stochastic modeling approach is investigated. As this model concentrates on the motion of individual particles, we also refer to it as a microscopic approach. In contrast, traditional deterministic models concentrate on macroscopic quantities such as concentrations of marked particles. The stochastic approach is conceptually simple and can be formulated directly from ideas about the physical transport of individual particles. The stochastic model has been proposed in a series of papers by Dehling, Hoffmann and co-authors e.g., Dehling et al. (1999), and successfully applied to the computation of residence time distributions in continuously operated fluidized beds. In this thesis we explore the stochastic approach for a variety of other experimental situations. The original Dehling-Hoffmann model is suitably modified for each case.

1.2 Aim and framework of this thesis

This thesis project was conducted under the collaborative supervision of Mathematics and Chemical Engineering departments. The main goal of this research project was to develop and adapt stochastic modeling approaches to certain fluidized bed reactors, and to experimentally determine the true flow characteristics of particles in these kinds of fluidized beds. The data for verifying the stochastic models came both from our own experiments and from other research groups. The work in this thesis comprises two main aspects: the first aspect focuses on using a stochastic approach to model different types of fluidized beds; the second aspect deals with the experiments and analyzing the data from each experiment.

A review of the available literature about fluidization is given in Chapter 2. These sections also introduce some of the basic concepts and definitions that will be used throughout the thesis, such as the physical properties of particles and the mechanisms of transportation of particles in fluidized beds.
Chapter 3 provides an introduction to a mathematical model, which is based on a stochastic approach and Markov chain processes. The concepts and the history of stochastic models in fluidized beds are also described here.

A stochastic model is presented in Chapter 4 for freely bubbling fluidized beds that was verified by a number of experiments using a hi-tech detector, Positron Emission Tomography (PET). Miniature fluidized beds were built to accommodate the dimension limitation of the PET scanner, 10 and 15 cm in diameter with a height of 83 cm in total.

Two main types of experiments were conducted; one was a single tracer experiment and the other was a pulse tracer experiment. On the basis of the pulse tracer experimental results, a one-dimensional stochastic model has been developed to describe the concentration of marked particles in fluidized beds in different heights and positions in the bed. The dispersion coefficient was calculated and also the wake flow rate. The stochastic model indicated that the radial dispersion was very small in comparison to the vertical dispersion and thus can be neglected. Experimental data and model results are also compared in this chapter. The results show the vertical particle transport to far exceed that expected in bubble wakes. This is attributed to “gulf streaming”. In spite of this, the model accounts qualitatively for all the observed phenomena.

In Chapter 5, the stochastic model is extended to incorporate a fluidized bed with “baffles” (sieve-line horizontal screens spanning the bed cross-section). The segregation mechanism of binary mixtures of particles inside a fluidized bed incorporating a series of baffles was studied and modeled. The resulting model is found to describe the trend-line of mixing and segregation of binary mixtures satisfactorily. The experimental fluidized bed used to obtain the data for modeling was the same as that used in Chapter 8 for the classification of metal powders.

Chapter 6 introduces a sophisticated stochastic approach to another kind of fluidized bed namely a slugging fluidized bed. The results from the stochastic model were compared with experimental data from Abanades and Atarés (1998) and were found to be in satisfactory agreement. The application of the stochastic model to slugging fluidization demonstrated its effectiveness for modeling various types of processes involving particles.

Chapter 7 introduces a model for mixing and segregation in a batch fluidized bed of binary mixtures. This model is completely different from the models studied in the other chapters in that it takes interaction of particles into account.
A case study of classified particle mixtures based on density differences is explained in Chapter 8. An attempt to use a new set-up, a fluidized bed equipped with vibrating internal baffles, is investigated. The experiment and results are described and discussed.

### 1.3 Lists of publications in support of this thesis

The following papers were published in support of this thesis:


1.4 References


