J. F. Davidson and D. Harrison (Editors).

FLUIDIZATION*

Reviewed by S. S. Zabrodskii

The book "Fluidization" was published by Academic Press in 1971. Its authors are 23 experts in 10 countries on 4 continents, which is a strong indication of a universal interest in fluidization and of a widespread research development.

The book is made up of 19 chapters. The titles indicate the depth to which this subject has been covered.

The first chapter "Fluidization Modes" describes the well known Zenz phase diagram, which comprehensively explains the transitions of disperse systems from one hydrodynamic state to another — including the transition from one fluidization state to another. A new suggestion is made here that three-dimensional phase diagrams be used.

An attempt is also made in this chapter to explain, in simple physical terms, the particular location at which gas flames periodically merge after passage through the grid holes (they merge underneath, within the zone of maximum head of fluidized material). Inrush of material into the lower space in a forming bubble is suggested to trigger the lift mechanism.

The second chapter "Minimum Fluidization and Homogeneous Systems" does not cover much of the work done in this field. No mention at all is made of the interpolation formulas developed by O. M. Todes and his associates, for instance, which are most convenient for calculating minimum fluidization. The authors of this chapter furnish data on fluidization under pressure, referring to experimental work where pressures of 14-40 atm have been attained, but do not mention the research done by Soviet scientists with much higher pressures (I. P. Mukhlenov and associates, G. P. Sechenov, and V. S. Al'tshuler).

The third chapter deals with the hydrodynamic theory of a fluidization bed, based on treating the latter as a system of two mutually penetrating and interacting continua. It discusses problems of linearization in the stability analysis of homogeneous fluidization and some aspects of nonhomogeneous fluidization. Neither here do we find even one reference to the theoretical work done by the Soviet researchers Yu. A. Buevich, V. P. Myasnikov, Yu. A. Cherepanov, I. N. Taganov, et al.

It is noted here that no satisfactory theory of bubble formation has been developed yet, and the view is stated that such a theory will evolve only from the solution to a system of nonlinear equations of motion.

As to the theories of bubble motion in a fluidization bed, the disapproving opinion of the author of this chapter about the assumptions on which they are based could be corroborated by the discrepancy between tests and calculations which have been reported at the Fourth International CHISA Congress (in 1972).

The fourth chapter describes properties of bubbles in a fluidization bed which can be observed in experiments. A valuable aspect of this chapter is that it puts together a great deal of essential material, scattered all over original articles, on methods of tracing bubbles and their shapes, measuring their lift velocity, analyzing the mechanisms of their fragmentation and merger, and examining the motion of solid particles induced by bubbles as well as the associated gas flow. Of interest are data pertaining to the strong effect of "insignificant" bed expansion beyond the stability limit on the particle mixing process.

The fifth chapter shows results of laboratory tests and pilot runs performed at high gas velocities making the process go into the piston mode. Attention is focused on the description of various kinds of "pistons" appearing in tubes of rather large diameter (50-500 mm) with particles of the above 50μm

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fraction. In this case pistons are, so to speak, straightened gas bubbles of constant dimensions and a constant velocity — all determined by the tube diameter. Solid particles pour down along the walls of these pistons like rain, allowing them to rise rather freely. The actual hydrodynamic characteristics of developed pistons correspond closely to those theoretically calculated, but the calculated conversion rate is below the actual one and this is, probably, a result of intensive reaction in the grid zone.

Unfortunately, not enough data are given here pertaining to the perhaps most interesting aspect of the application of the piston theory to the design and construction of reactors, namely the feasibility of evaluating the effect of vertical inserts (tubes) in a fluidization bed and using as the basis for this the hydraulic diameter of the interstitial "channels." The data on bed expansion indicate that pistons may be formed in these channels, but no comparable data are given on chemical reactions.

The sixth chapter analyzes the rheological behavior of fluidized systems and the view prevails here that a further development of the respective hydrodynamic theory is possible only with a proper consideration of static and dynamic interactions between particles of the solid phase. This would, in turn, make it possible to replace the theory of potential flows by a more realistic one, although this would require an amassment of rheological test data. Considerable space in this chapter is allotted to an evaluation of procedures for testing under various conditions. Existing test data are analyzed and a certain particle orientation undetectable by x-rays is hypothetically suggested to cause the sometimes observed reduction in the effective viscosity of the system during an increase in the shear rate.

The large seventh chapter "Mixing in a Fluidization Bed" is approximately 90 pages long, quite justified by the importance of this subject, and contains all kinds of information about the first experimental studies, the more recent experiments with the use of tracers, about theoretical models, about the use of chemical reactions for the study of mixing, and, finally, about mixing in beds fluidized with liquid droplets. A shortcoming of this chapter is the somewhat imprecise presentation. Thus, it is not always clear here what applies to the gas and what applies to the fluidized material. It is noted, correctly, that not enough has been learned about the effect of inserts in a fluidization bed on the mixing processes, but it further detracts from the presentation that nothing is said about material published on this subject in the Soviet and in the Japanese technical literature.

When mentioning (p. 301) the results of large-scale experiments by Askins and associates (in 1951) and by Dankwertz and associates (in 1954), it should have been added that the research of the former concerned the behavior of a gas in the emulsion phase of fine-dispersion beds, where the mixing of the gas and solid particles is essentially mechanical, while the research of the latter concerned the behavior of a gas in the entire fluidization system (including bubbles which move through it with almost complete dislodgement).

The eighth chapter describes, unexpectedly before the chapters on heat and mass transfer, the performance of fluidization beds as catalytic reactors. The development of mathematical models is discussed here, along with the problems of transition from laboratory apparatus to large-scale apparatus — including problems in selecting the horizontal and the vertical bed dimensions as well as the operating gas velocity, the particle size, and the type of gas distributor.

The problems of upscaling are analyzed on the basis of the simplified concept that, as the reactor diameter increases, the reactor performance worsens because the passage of large gas bubbles proceeds more and more along preferred paths — especially with a low-grade gas distributor.

The ninth chapter deals with mass transfer in fluidization beds. Considered are the mass transfer between bed and body, or wall, the interphase mass transfer, and determination of the reactor height for attaining the maximum degree of conversion (the conversion problem) or the maximum total product output (the selectivity problem). As an example, the oxidation of naphthalene serves to illustrate that the selectivity problem is tied to more complex functional relations than is the conversion problem, but that the added complexity is compensated by a weaker effect of gas mixing inthe emulsion "phase" on the optimum reactor height — although a flow with complete dislodgement is desirable.

The tenth chapter, which deals with the important problem of heat transfer, is not a particularly good one. The statement in the introductory section about a fluidization bed being "almost isothermal" is rather outdated. This concept has evidently made the authors ignore the work done concerning one of the three most important aspects of heat transfer in a fluidization bed: the effective thermal diffusivity. This concept puts up an artificial obstacle to the treatment of data on heat transfer at low fluidization numbers and during moderation with inserts, or during vibrofluidization; it is an obstacle to an understanding of the important details in the complex heat transfer at a wall at high temperatures. There is nothing said in this

chapter about the heat transfer between a vibrofluidization bed and immersed surfaces, about the effect of static electrification on the heat transfer, and no explanation is given for the effect of the particle size. The authors do not reveal the new developments in the "packet model" treatment of heat transfer between bed and wall, where account is taken of the different velocities of heat wave propagation through the solid phase and through the gaseous phase in a dispersion system (research work done at the Institute of Heat and Mass Transfer, BSSR Academy of Sciences), nor is anything said about another method of analysis (research by Botterille, Gabor, and at the Institute of Heat and Mass Transfer). Quite limited in scope and somewhat obsolete is the material presented here concerning the heat transfer between bed and wall at high temperatures. Along with all these and other shortcomings, the chapter is overloaded with less important material such as calculation of heat transfer coefficients for a bed and wall under various boundary conditions, the pseudokinetic equation of the (10-38) type, or the analysis of equilibrium, external, and internal heat transfer between gas and solid particles, presumably the three stages of the process, which seems rather farfetched. Besides, the last "stage" with characteristically low values of the Biot number for a fluidization bed is altogether insignificant or is usually accounted for in the external heat transfer according to the well known simple Kitaev method.

Another item for comment are the improper bibliographic references: more recent rather than the original sources are cited. This, by the way, we find wrong in some other chapters too.

Valuable in this chapter are the test data on heat transfer in beds with vertical or horizontal tube bundles, but these data should have been compared with those obtained by N. V. Antonishin (in 1963) for horizontal bundles.

The eleventh chapter "Analogy between a Fluidization Bed and Fluids" analyzes those processes in a fluidization bed which correspond to the fusion of solids and the evaporation of liquids, along with a few other aspects of the analogy.

V. L. Prizhetslavskii should have been mentioned here, who before others in the USSR studied the partition of mechanical mixtures in a fluidization bed.

The twelfth chapter deals with desiccation. It is to be commended that the author has skilfully utilized the space in this short chapter with a concise presentation of the subject matter and with an elaborate list of references most of which are easily found in the technical literature (not dissertations) and cover a given topic in detail.

As is well known, packing a bed or inserting barriers can be important means of controlling its hydrodynamics. The thirteenth chapter reviews many studies concerned with the effect of horizontal and vertical barriers and of stationary packing on the fluidization process. A lot of material recently published in the USSR and in Japan is missing, however, such as certain studies concerning the heat transfer with immersed surfaces, the effective thermal diffusivity and the expansion of beds moderated by means of packing (Institute of Heat and Mass Transfer, BSSR Academy of Sciences), and studies concerning the effective thermal diffusivity of fluidization beds with horizontal meshes and grids (Institute of Heat and Mass Transfer, BSSR Academy of Sciences).

It is noted that moderation of a bed, while useful for effecting chemical reactions, may, however, set up stagnation zones and impede the dissipation of heat. This, in the authors' opinion, is the reason why the introduction of moderate beds into large-scale production plants has been so slow. The main reason is, however, that evidently not enough fundamental research has been done on moderated systems and not sufficient field test data are available. In the final analysis, the basic question is still left open, namely whether (and when) a small apparatus with moderated fluidization bed may be regarded as a single cell of a large industrial apparatus and, then, how are such large aggregates to be designed and built.

Another important practical problem not yet sufficiently explored is the erosion of material from a fluidization bed, and this problem is dealt with in the fourteenth chapter of the book. This chapter analyzes the mechanism by which the fine fractions of particles are blown off and washed off, also test data and their correlation are evaluated here. No reliable correlations have been established so far for calculating the erosion with a free separation height above a bed of lower height. It is noted here that these problems have been discussed thoroughly in the monograph by Cooney and Levenspiel ("Fluidization", Wiley, New York, 1969), and it is suggested that erosion be tentatively calculated according to the empirical Lewis formula with the Cooney—Levenspiel modification.

The fifteenth chapter deals with the fluidity of the dense phase in a fluidization bed, it analyzes the

flow through orifices and nozzles, also the flow a fine-dispersion material along vertical tubes. A great deal is known qualitatively. The peculiar characteristics of a bed discharge through small orifices have to do with a partial defluidization before passage through such orifices. The quantitative analysis is based on predominantly empirical relations. A given stable flow of a fine-dispersion material through tubes is established with difficulty and not by design, as a rule, but by regulating the aeration of that material and the positions of the valves.

The sixteenth chapter "Systems with a Dilute Phase" contains much information about horizontal and vertical transport of solid particles by means of gas streams, including transport through a dense phase; new data are presented on horizontal pneumatic transport. In the paragraphs on a suspension bed there is, however, conspicuously no reference made to the work done by I. M. Fedorov (in 1955) and Z. R. Gorbis (in 1964), also some of the calculation formulas in this chapter are in a rather poor agreement with test data. With such a chapter included in the book, it would seem logical to add, at least briefly, something about the heat-and-mass transfer in that kind of system, especially since the heat-and-mass transfer as well as the chemical reactions in the transport lines of fluidization apparatus become often very significant.

The seventeenth chapter deals with the spouting bed and has been well organized, containing a long bibliography and including important information not only about the hydrodynamics but also about the heat-and-mass transfer and the practical application of such a system. It does not present data, however, obtained at the Institute of Heat and Mass Transfer (BSSR Academy of Sciences) as a result of feasibility studies pertaining to the development of heavy-tonnage apparatus with spouting beds and a low hydraulic drag, it does not discuss the advantages of pulsating the gas stream, nor does it discuss the outstandingly high thermal efficiency and simple construction of multistage apparatus with a spouting bed.

The eighteenth chapter presents a broad survey, not yet found in other monographs, of studies concerning the three-phase fluidization process. All three basic variants of three-phase fluidization are covered here: fluidizing a bed of particles with concurrent ascending streams of gas and liquid, fluidization with an ascending gas stream through a bed sprayed with liquid from above, and (very briefly) fluidizing a bed of light-weight particles with a descending stream of heavy liquid and simultaneous gas injection (through a limiting grid above the bed). Another variant of three-phase fluidization is also mentioned, namely fluidization with two immiscible liquids, which may be of interest in extraction processes.

The concluding nineteenth chapter discusses certain general problems not pertaining specifically to any individual technological process but encountered in the design of large fluidization apparatus. Discussed here are the characteristics of gas distributors, the behavior of gas bubbles and of the solid material in such apparatus, and the management of material routing through multistage fluidization plants. All these problems are of tremendous practical and scientific interest, but they have been treated rather scantily and not enough data are available for answering many essential questions. The authors enumerate well known reasons for this deficiency in published information on large fluidization apparatus, such as trade secrets and actual ignorance of what occurs in a large system — due to the difficulty in performing full-value experiments under industrial conditions and due to the common tendency of practically minded individuals to terminate a study project after economically satisfactory results have been obtained.

It strikes one that the book has been too "freely" edited. For instance, there appear isolated chapters, completely unconnected with one another, dealing with the rheology of fluidization systems (Chapter 6), the analogy between such systems and fluids (Chapter 11), and the fluidity of the dense phase in a fluidization bed (Chapter 15).

On the whole, this book can hardly be called a monograph, since it lacks in completeness in presenting even concisely, at least, the modern state of the art in areas of interest here. Nevertheless, this book should be of considerable value to the Soviet reader, since it contains a wide range of material and it indicates the state of the art in fluidization research in Western countries, also because the views of individual experts — the authors of each chapter — are given here on respective specific problems.