REVIEWS

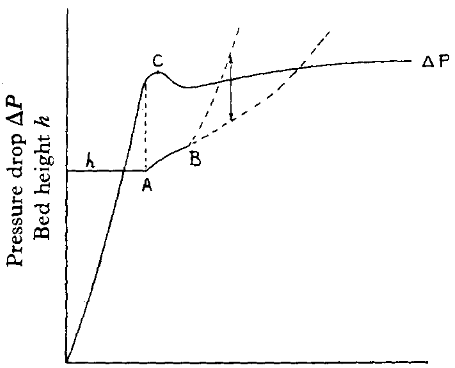
Fluidization, edited by D. F. OTHMER. New York : Reinhold Publishing Corporation, 1956. 231 pp. 56*s*. or $7.00.

Fluidization is a modern chemical engineering technique which raises a number of new problems in fluid mechanics. The word describes a process whereby a bed of small solid particles is given the properties of a fluid by blowing gas upwards through the interstices, and may best be introduced by describing a typical laboratory experiment. Suppose a vertical pipe contains sand, which is supported to a depth of a few inches by a wire gauze, and that air is blown up through the bed. At small rates of flow, the air stream suffers a pressure drop depending on the flow and on the size of the sand particles, but does not affect the arrangement of the bed. At a sufficient flow rate, however, the overall pressure drop is enough to support the weight of the bed, which must then expand to accommodate any further increase in flow. The expansion may be as much as 30%, and the fully expanded or 'fluidized' bed has many properties in common with a liquid; its upper 'surface' remains horizontal when the containing vessel is tilted, and it offers little resistance to the movement of objects floated on the surface. If air is blown at a still greater rate through the fluidized bed, it ceases to escape uniformly through the interstices, but forms bubbles which push violently through the animated particles so that the bed has the appearance of a boiling liquid. With a much greater airflow, whole blocks of particles are carried bodily up the tube to several times the original bed height, and then disintegrate and fall back, giving a pulsating motion. Finally, the mean air velocity in the tube exceeds the velocity of free fall of the particles, which are then carried out of the tube.

A fluidized bed is a very attractive means of bringing a gas into contact with a solid, and has lately been applied to many chemical processes in which contact between a gas and a fixed bed of particles was formerly used. If heat is produced by chemical reaction within the bed, temperature gradients are reduced by the boiling action of the particles. This means that heat can be removed by cooling coils within the bed, or by pneumatically conveying the particles to external coolers. When the particles are a catalyst, and are subject to fouling, pneumatic conveying can be used to remove them from the reacting bed for regeneration. Because of these advantages, fluidized beds have come into use on a very large scale for petroleum processing, roasting of ores, and drying of solids.

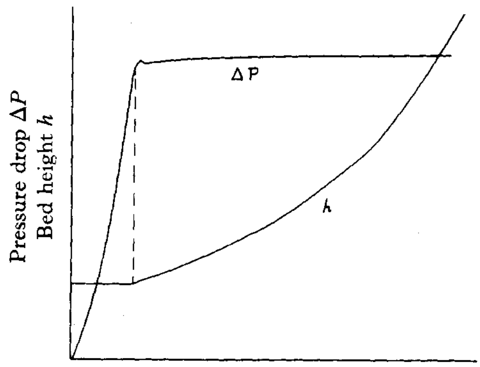
This book is a series of chapters on fluidization by leading American chemical engineers. The first three chapters deal with fluid mechanics and heat transfer characteristics, and the remaining six describe various processes using fluidization and also outline some operating and control techniques. The first part of the book is therefore of direct interest to workers in fluid mechanics. Moreover, they have excellent reasons for not ignoring the applications described in the second part; it is good for them to know what questions the engineer would really like to answer, since even mathematicians usually like to solve useful problems.

The first two chapters describe measurements that have been made on small-scale fluidized beds and their correlation. Of these correlations, the simplest are those which give overall pressure drop and bed height as functions of airflow, and have the form shown in figure 1. *A* is the first point at which the pressure drop is sufficient to support the weight of the bed. Thereafter the bed expands with increasing airflow, but is quiescent up to point *B*. Higher flows induce bubbling and oscillatory motion, and the bed height fluctuates between limits shown by the dotted lines. There arises the question, are the particles fixed in position between *A* and *B* ? If so, it can be presumed that the bed expands by changing from a closely packed configuration to a loosely packed one. The slight pressure rise from *A* to *C* might be caused by particles bridging the tube in modes of closer packing. Point *B* would correspond to the loosest possible packing for particles in contact.



Air flow

Figure 1.



Water flow

Figure 2.

The characteristics of a particle bed fluidized by water are somewhat different (figure 2). In this case there is a unique bed height for all flow rates, there are no bubbles, and the particles are evenly spaced. Under what circumstances do increments of flow lead to the formation of bubbles rather than increased spacing of all the particles? This might be considered as a stability problem. Suppose that a number of equal spheres are held at points on a uniform lattice, and that fluid is blown through the interstices at a rate sufficient to support the weight of each sphere. If a particular sphere is released, so as to be free under the action of drag and gravity forces, under what conditions will it be stable in the original position ? There is experimental evidence to suggest that the relative densities of the spheres and fluid would be important, because lead spheres give bubbling when fluidized by water, but glass spheres do not; glass beads give bubbling when fluidized by air, paper cubes do not!

The authors of the present book do not give much attention to this kind of problem. As engineers, they are concerned with correlations which can be used for design, with mechanical features of plant, operational details, and applications to various processes. For those who are interested in finding out how fluidization works, the first three chapters are the most stimulating. These chapters deal respectively with fluid mechanics, heat and mass transfer, and graphical methods of analysis for fluidized systems. The first two chapters describe correlations devised in an attempt to relate the dimensionless parameters of the fluidized system. This method of correlation has been very successful for relatively simple mechanical systems; but for complex systems such as fluid flow through a fixed porous medium, its application has been less successful. For example, when matter diffuses from the surface of the particles to the fluidizing gas, a mass transfer factor j_d can be correlated with a modified fluid Reynolds number R. The correlation given in chapter 2 covers values of R between 1 and 10^4, and of j_d between 0·01 and 1·5. Results due to many experimenters are said to fall on a single line, although, at a given R, the largest j_d may be six times the least. Nevertheless the correlation is useful, and it is difficult to see how else to deal with such a complex problem.

The third is perhaps the most original chapter, and deals with a wider range of problems than is normally implied by the word fluidization. All types of combined fluid and particle flow in a vertical pipe are represented on a diagram, with gas velocity as abscissa and vertical pressure gradient as ordinate. Roughly speaking, the particles will behave in much the same way as a liquid. Thus, if they are restrained at the bottom, the particles will pack together, and, in the presence of an upward flow of gas, can be transferred downwards through a valve, or will flow from one limb of a U-tube to another under the influence of gravity. As described above, the gas can bubble through a fluidized bed of particles, or, if the containing tube is small, alternate slugs of gas and particles will be formed. Under different conditions, the fluidized bed of particles is 'atomized', and the separate particles travel through the tube at some distance from one another. The particles will move upwards in this manner if the gas velocity is very high, and downwards if the gas velocity is very low and the particles are not restrained at the bottom of the tube. Such an analogy with the behaviour of liquids is difficult to express quantitatively, but is useful in designing apparatus for particle transfer.

The remaining chapters deal with process operation, but are not without interest for research workers who wish to come to grips with the real practical problems. These chapters would have been better if more numerical information about large-scale plant had been given. The application to large scale plant of the correlations in the earlier chapters is somewhat dubious without direct verification from big equipment.

A general criticism is that the book suffers as the result of being based rather too directly on a symposium. Thus each chapter is written in the conversational style of its author; the writing is often ungrammatical, and many passages are scarcely intelligible, although the colloquial style is sometimes refreshing. The book will not become a classic on the subject; it is a progress report which should stimulate the chemical engineer to make wider applications, and the research worker to make further efforts to understand the mechanism of fluidization.

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