POWDER TECHNOLOGY SERIES

POWDER MIXING

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CHAPMAN & HALL

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Powder Mixing

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Many materials exist in the form of a disperse system, for example powders, pastes, slurries, emulsions and aerosols. The study of such systems necessarily arises in many technologies but may alternatively be regarded as a separate subject which is concerned with the manufacture, characterization and manipulation of such systems. Chapman & Hall were one of the first publishers to recognize the basic importance of the subject, going on to instigate this series of books. The series does not aspire to define and confine the subject without duplication, but rather to provide a good home for any book which has a contribution to make to the record of both the theory and the application of the subject. We hope that all engineers and scientists who concern themselves with disperse systems will use these books and that those who become expert will contribute further to the series.

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Wordfinder index

This index can be used to find the first occurence and definition of technical terms used throughout the book.

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1 Mixing technology

1.1 AN HISTORICAL OVERVIEW OF POWDER MIXING SCIENCE AND TECHNOLOGY

The art of mixing powders is an ancient one. Wall paintings from Egyptian tombs show technicians mixing powders using a pestle and mortar to create cosmetic mixtures and medicines. The mixing of the ingredients of gunpowder has a long history reaching back to at least around 700 BC. A manuscript dating from that time warns Chinese technicians in a discussion of the art of gunpowder making that

> Many people when mixing gunpowder ingredients have caused fires which singe the beards of those engaged in the manufacture of such powders and burns down the building.

The making of cakes and pastries is another ancient art involving the mixing of powders. Today the cosmetics, pharmaceuticals, explosives and food industries are major users of mixing equipment.

One of the problems that the student soon encounters when studying the scientific literature on powder mixing science and technology is a confusing terminology. This confusion arises from the fact that powder mixing is an activity of many industrial technologies and there has been little or no attempt to co-ordinate the evolution of a systematic and carefully defined vocabulary to be used by scientists from many different technical backgrounds. Throughout this text we will discuss historical terminology usage in powder mixing and suggest a consistent set of terms, which will be used throughout the book. To provide ready reference for the reader to the way in which words are used in this text, the wordfinder approach has been adopted. In this technique a word is defined the first time that it is encountered in the text. The first occurrence is highlighted using a bold font and listed in the wordfinder index placed at the beginning of the book. When a word is encountered later on in the text, the reader may wish to refresh his or her memory with regard to the technical term and the wordfinder index will direct the reader to the definition location. Another reason for discussing vocabulary used in powder mixing is the need to organize a consistent set of key words to be used to retrieve useful research papers from the world's rapidly expanding scientific literature. I once did a computer search for literature on the behavior of suspensions of solids in liquids and received from the computer a listing of a paper entitled 'The Theoretical Behaviour of Ideal Suspensions'. At some expense a copy of the paper was obtained, only for me to discover that the investigations described in the scientific publication were concerned with the performance of springs in automobile suspension systems!

Unless scientists pay more attention to the organization of their literature in such a way that the computer can be used to store and retrieve the information, they will find themselves floundering in a sea of irrelevant literature. One of the projects underway at Laurentian University is to take the listing of scientific publications presented in this book and annotate it with key words so that an information retrieval system can be organized on the computer system being used to print the reference list. This is obviously an ongoing project, and in the future it may be possible to issue the literature list with annotated key words, as a separate entity from the list of references used, to make this book useful to the working industrial scientists.

The first thing to note about the vocabulary used in this book is that the term **blend** will not be used, except when it occurs in the name of a piece of equipment. Two main contributory sources to the development of the English language are root words from Latin and Greek, referred to as 'classical' languages, and root words from the Anglo-Saxon which is the parent language of English. As a consequence of the way in which the language is developed, there are many doublets in the English language which have virtually the same meaning, with one of the pair being from Latin root words and the other from Anglo-Saxon roots. This is the situation with regard to the words 'mix' and 'blend'. In the development of the vocabulary used in the book, we will often refer to the meaning of the root words of a technical term. Some readers may be impatient with the discussion of the origin of vocabulary, since they regard themselves as practical people who are anxious to get on with the job. However, a great deal of time and money is wasted by a failure to communicate precisely in a technology such as powder mixing. It is essential that words used in discussing or posing technical problems should be precisely defined and used consistently. For example, as we shall discuss later in this section, the word 'random' is used in a very sloppy way by various authors, and a failure to define the concept can result in two scientists talking at cross purposes and never focusing on the real problem.

The Latin root word *miscere* means 'to mix'. This root word has given us the word **mixture**, to describe the product of the physical intermingling of more than one finely divided component when those components retain their physical identity. A **mixer** is a piece of equipment in which a mixture is achieved. The word 'blend' comes from an old English root word *blanden* meaning exactly the same as the Latin root word. Therefore, blend and blender are doublets of mixture and mixer. Some investigators have used the word 'blend' to indicate the gradual addition of a minor ingredient to a mixture, but the usage is not universal, nor useful, and is not recommended or used in this text.

When discussing the problems of mixing technology it is useful to differentiate between two main classes of powders. One type, described as **free flowing powder**, is typified by such systems as coarse dry sand and coarse metal powders. In general, free flowing powders are relatively easy to mix, but the resultant mixture is prone to segregation of the components during subsequent handling procedures. **Cohesive powders** are ones in which the constituent fineparticles are aggregated to each other by forces such as electrostatic forces and liquid bridges caused by humidity. (The powder does not have to look moist to contain aggregates formed by internal moisture; this aspect of cohesive powder structure is discussed in greater detail in Chapter 3 on powder rheology. **Rheology** is the scientific term for the study of the flow of substances, a word derived from the Greek word *rheos* meaning 'to flow'.) The subject of moisture control of cohesive powder properties is very complex. In some situations one must reduce the environmental humidity to make it possible for powders to flow. In other situations, one must increase the humidity to avoid problems due to electrostatic charge. For example the environmental conditions in the laboratory at Laurentian University can vary widely, reaching 100% humidity in the summer when the temperature outside the building is close to 100° Fahrenheit, but in the winter, when the external temperature can be −20° Fahrenheit, internal humidity values can be so low that dry powder can climb up the walls of a plastic container because of electrostatic forces. Additives are available which can convert a cohesive powder, such as fine cement, to one that flows like water. Thus if one adds finely divided silica to the cement powder it can be transformed into a free flowing powder. These agents are known by names such as flowagent or glidants. Flowagents added to powdered ingredients in a mix can promote mixing but can cause problems later in the mixture handling. In general, cohesive powders are more difficult to mix than free flowing powders, but the resultant mixtures are far less susceptible to segregation during subsequent handling than free flowing powders.

Some scientists have used the words **particulate** to describe finely divided material. The term is not used in this book because particle physics to physicists, and many other scientists, is the study of fragments of the atom. Any computer-aided literature search based on the word 'particle' would flood the enquirer with publications on muons, neutrons, electrons etc. The term **fineparticle** is a unique term which can be used to describe the study of the physical behavior and properties of finely divided materials including sprays. The term 'fineparticle' will be used throughout this text. The kind of confusion that can arise when using the word 'particulate' is illustrated by Beddow in his textbook [1] when he makes the statement

> The most immediate savings which can be released in the operation of particular mixes is that of mixing time.

In this sentence he does not mean special mixtures but particles being mixed. The confusion is obvious.

Even though the art of mixing powders is an ancient tradition, the science of powder mixing is relatively new. Thus, as pointed out by Karl Sommer in an introduction to the history of powder mixing,

> Despite the long history of dry solids mixing, or perhaps because of it, comparatively little is known of the mechanisms involved. All the experience that has been gained ever since solids were first mixed by man some 30,000 to 40,000 years ago has been handed down through the ages formerly from medicine man to medicine man, now a days from foreman to foreman. By continuous trial and error a degree of perfection has been achieved that could hardly been improved upon by scientific approaches [2].

Although there is some truth to these comments on the history of powder mixing, there are many industrial scientists today who would not regard the mixing technology available as constituting a body of knowledge which is a state of perfection that could hardly be improved upon. This is because industry is involved in a never ceasing effort to lower costs, improve efficiency and evolve specialist mixtures. J.K. Beddow, in another review of the history of powder mixing, comments that

> Prior to 1940 there has been little incentive to develop efficient powder mixing equipment for the powder processing industries as a whole. Since the power consumed by mixing equipment was not large and the economic gains that could be achieved by improved mixer design were not a sufficient stimulus to initiate research, effort focused on better design of mixing equipment [1].

The beginning of the scientific study of mixing equipment and mixture structure can be traced back to a pioneering paper published in 1943 by P.M.C. Lacey [3], on the structure of mixtures when the ingredients have had their positions within the mixture randomized. Beddow points out that Lacey's paper had only one reference, to a book on the theory of statistics [1]. The word **stochastic** is used by mathematicians who study randomly varying systems. The word comes from a Greek word meaning 'I guess'. Thus if we are throwing pairs of dice in a game of chance, the number that appears when the dice are thrown is known as a **stochastic variable** because we can only guess which number will be generated by the throw of the dice. After the pioneering work of Lacey, there was a very rapid growth in the literature on the stochastic aspects of powder mixing. Beddows has commented on the growth of this literature by pointing out that in the first major work on powder science published in 1948, Dalla Valle's pioneering work called *Micromeritics*, the subject of mixing was not discussed [4]. (Incidentally, it should be noted that Dalla Valle advocated the use of the term 'Micromeritics', which he coined as an overall term for the subject of powder science and technology, including spray technology. The name is still to be found in some scientific publications but has not been widely adopted.) In 1966 the text *Particulate Technology*, by Clyde Orr, devoted 30 pages to the subject of powder mixing [5].

The rapid growth of the literature on powder mixing is evident by the fact that a bibliography published in 1972 contained 350 references and one prepared in 1976 contained 650 references [6]. As one contemplates such a wealth of literature, one would anticipate that all of the mixing problems of industry could be solved if only the busy technologist could find time to read the accumulated wisdom represented by such a list of references. In fact after the 1970s, interest in the scientific aspects of powder mixing appeared to wane, and a scientist from the United States reviewing a book published in 1986 described powder mixing as

> An important but academically unfashionable subject in the United States [7, 8].

However, academics who have apparently shied away from powder mixing for 10 to 15 years may now be poised for another major set of investigations into powder mixing because of the current interest in chaos and catastrophe theory [9–12].

The fact that very little changed in the art of powder mixing during the 1970s and early 1980s is emphasized by some comments made by Weidenbaum at the commencement of his chapter on the mixing of powders in a textbook edited by Fayed and Otten [13]. In these comments he pointed out that the chapter in the book was the direct reproduction of a chapter written some 12 years earlier for Perry's handbook of chemical engineering [14]. He said that it was being published unchanged because nothing noteworthy had happened in the intervening period. The apparent failure to use the information generated by 30 years of academic investigation is commented on in a chapter on the mixing of powders written by J.C. Williams of Bradford University (one of the acknowledged international experts on powder mixing) in a book published in 1986. Dr Williams states

> During the past 30 years there has been much work done at the universities in the study of solids mixing but the results of this effort are not yet widely applied in industrial practice [15].

At first sight it is surprising that such information is not being used by the industrial community. After conducting workshops for industrial scientists concerned with powder mixing for several years, I think that one of the major problems is that the scientists carrying out the investigations into powder mixing processes in the 30-year period leading up to 1986 tended to use complex mathematical symbolism and vocabulary remote from the background of those who had to use powder mixers. For this reason, a great deal of the information generated in the academic world was inaccessible to the practical scientist. This is one of the reasons why excessive use of mathematical symbolism is avoided in this book. When I began to plan this book, I started to look again at some of the high-powered scientific papers on the statistics of powder mixtures that I had collected over the last 40 years. As I re-read them I remembered some comments made by Dr J.E. Gordon in one of his delightful books on material science and structures. These books are *The New Science of Strong Materials, or Why You Don't Fall Through the Floor* [16], and *Structures, or Why Things Don't Fall Down* [17]. The titles are a good intimation of the flavor of the books. I personally gained a better appreciation of the science of materials through reading these two paperback books than from a university course at the second year honors level. When commenting on textbooks of elasticity, Dr Gordon made the comments

> Since the subject became popular with mathematicians about 150 years ago, I am afraid that a really formidable number of unreadable incomprehensible books have been written about elasticity. Generations of students have endured agonizing boredom in lectures about materials and structures. In my opinion, the mystic and mumbo-jumbo is overdone and often beside the point. It is true that, the higher flights of elasticity are mathematical and very difficult but then, this sort of theory is probably only rarely used by successful engineering designers. What is actually needed for a great many ordinary purposes can be understood quite easily by an intelligent person who will give his or her mind to the matter. ... The engineering professor is apt to pretend that to get anywhere worthwhile without higher mathematics is not only impossible but that it would be vaguely immoral if you could. It seems to me that ordinary mortals like you and me can get along surprisingly well with some intermediate and I hope more interesting state of knowledge [16].

If one substitutes 'powder mixing' for the word 'elasticity' in the above quote, you have a statement of how I feel about some of the complicated theories and mixing indices of published work on powder mixing.

In all fairness however, it should be pointed out that after Dr Gordon has severely criticized the boring mathematical complexity of textbooks, he goes on to add that one does, however, need a basic mathematics survival kit to be able to proceed in a quantitative manner. He writes:

> What we find difficult about mathematics is the formal, symbolic presentation of the subject by pedagogues with a taste for dogma, sadism and incomprehensible squiggles. For the most part, wherever mathematical argument is really needed, I shall try to use graphs and diagrams of the simplest kind [16].

If I can do this for powder mixing science and technology as successfully as Dr Gordon did it for structures and materials, I will be satisfied.