Wolfgang Pietsch

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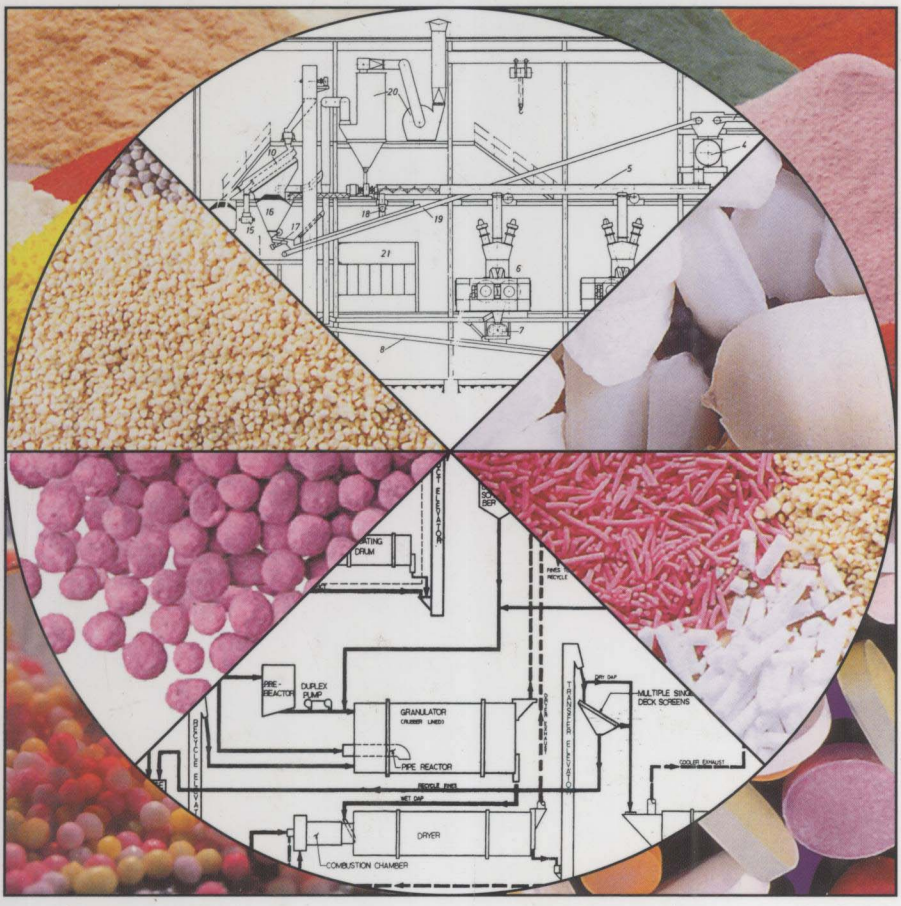
Agglomeration in Industry

Occurrence and Applications

Volume 1



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Preface

When this book was first planned, the idea was to combine in one volume concise descriptions of agglomeration phenomena, technologies, equipment, and systems as well as a compilation of the applications of agglomeration techniques in industry. The latter was intended to demonstrate the widespread natural, mostly undesired occurrences of the phenomena and possible ways of avoiding them as well as the old, conventional, and new, varied beneficial uses of the technologies.

However, it soon became obvious that, in its entirety, this project was too extensive and required much more time than anticipated. Therefore, it was decided to split the subject into two complementary books.

The first book, *Agglomeration Processes – Phenomena, Technologies, Equipment* (ISBN 3-527-30369-3) was published by Wiley-VCH, Weinheim, Germany, in 2002. It covers the fundamental phenomena that define agglomeration and industrial technologies and equipment for size enlargement by agglomeration. Applications are mentioned in a general way throughout this text but without going into details.

This second book is an up-to-date overview dealing with the occurrence and key applications of agglomeration, including size enlargement in pharmaceutical, food and animal feed, chemical, fertilizer and agrochemical, mineral, building material and ceramic, metal, solid fuel, and other industries. Furthermore, the book emphasizes recent developments at the level of single particles and applications of agglomeration phenomena in nanotechnologies.

Many people, institutions, and companies have contributed to the two books.

First and foremost, I wish to thank my wife Hannelore for her support and understanding, particularly during the years when I was compiling these books. They are both dedicated to her. Without my wife's active participation in preparing almost all my publications, including the first textbook entitled *Size Enlargement by Agglomeration*, which is a major reference for the current two books, and her acceptance that I was not available for many hours almost every day during much of two decades, these publications could not have been completed.

It is impossible to acknowledge all the help that was provided by a large number of individuals and companies. Chapter 15.1 is a list of vendors and other organizations, which mentions those who have, in one way or another, contributed as well as some others that might be of interest as potential contacts for the readers of these books. While I have decided not to clutter the text with references, sources have been acknowl-

edged if figures or tables were provided by or are based on input from particular companies. The Disclaimer at the beginning of this book should be referred to when using such information.

Chapter 13 lists literature references. The earlier textbook, *Size Enlargement by Agglomeration*, contains treatments and many references relating to the developing science of the unit operation and covers the sizing of agglomeration equipment in some detail. Since the emphasis of the new books is on industrial applications, rather than theory, the earlier book should be referred to for the theoretical background. Information on the availability of reprinted copies of *Size Enlargement by Agglomeration* (Wiley, 1991) is available in Chapter 13.1 as a footnote. I have also contributed major chapters on agglomeration to two other books, portions of which are used in this book. The other books are: *Handbook of Powder Science and Technology* (Eds: M. E. Fayed, L. Otten), 1st edn, Van Nostrand Reinhold, New York (1983) and 2nd edn, Chapman & Hall, New York (1997). Full references can be found in Chapter 13.1.

Since size enlargement by agglomeration is one of the four unit operations of Mechanical Process Technology (see Chapters 1 and 2) and, for the design and construction of agglomeration systems and plants of any kind, many or all of the other unit operations are required together with the associated transport and storage technologies, often even in multiplicity, and the analytical methods are applied for process evaluation and control, the reader who is interested in the topic of this book should also learn about or have access to information on the other fields of Mechanical Process Technology (references in Chapter 13).

Finally, I wish to thank the following individuals who, as professionals and experts in their own fields, are or have been colleagues and/or partners in several continuing education courses over many years in the USA and in Europe and have agreed that their presentations and course notes can be used directly, adopted, or modified for this book. They are, in alphabetical order: T. van Doorslaer, W. E. Engelleitner, B. J. Ennis, M. E. Fayed, M. Gursch, D. C. Hicks, S. Jagnow, R. H. Leaver, R. Löbe, K. Masters, S. Mortensen, H. B. Ries, F. V. Shaw, N. Stanley-Wood, J. Storm, R. Wicke, and the late R. Zisselmar. Other major contributors were M. Karel, Y. Kawashima, the late B. Kaye, and H. Schubert.

Wolfgang Pietsch,
Naples, FL, USA,
September 2004

Contents

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1
Introduction

This book is complementary to the author's earlier books, *Roll Pressing* (1976/1987) [B.13b], *Size Enlargement by Agglomeration* (1991) [B.48], and *Agglomeration Processes – Phenomena, Technologies, Equipment* (2001) [B.97], as well as some major contributions to professional handbooks, such as *Size Enlargement by Agglomeration* (1997) [B. 71].

While *Roll Pressing* [B.13b] dealt exclusively with aspects of pressure agglomeration in roller presses, *Size Enlargement by Agglomeration* [B.48] covered the entire operation and some related fields from a fundamental view point. It described in much detail the newly evolving science of the natural phenomenon "Agglomeration", which has been used by living creatures, including humans and modern mankind, for thousands of years, and the technologies that were derived from it. In contrast, *Agglomeration Processes – Phenomena, Technologies, Equipment* [B.97] was trying to offer a complete, up-to-date compilation of the various agglomeration techniques and, in general terms only, their applications. To that end, in addition to introducing the properties of agglomerates and the specific characteristics of the different technologies, descriptions of equipment and their special features for particular uses as well as engineering know-how and information on specific peripheral equipment were the main topic of the book. Emphasis was on up-to-date practical knowledge, not theory.

The present book again does not claim to be a scientific publication. Agglomeration, both as a phenomenon and as the beneficial size enlargement of particulate solids, has become part of the newly defined interdisciplinary technical field of Mechanical Process Engineering and a science in its own right, as described earlier [B.97], (Chapter 2). Nevertheless, much of the research and development are phenomenological in nature and most of the designs for equipment and industrial plant still rely heavily on the experience and know-how of vendors as well as experts in the field. Therefore, after again reviewing the fundamentals of agglomeration in an even more abbreviated form, this book attempts to summarize and describe the occurrence of agglomeration in industry, the industrial applications of size enlargement by agglomeration, and other beneficial uses of particle adhesion. The latter, in particular, is found increasingly in new fields such as nanotechnology, life sciences, and even the communication industry (nanoelectronics).

Obviously, it is not possible to describe all the many occurrences of agglomeration and to cover every application of size enlargement by agglomeration in industry. Par-

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ticularly during the past 50 years, because of an increase in the production of fine and ultra-fine primary, intermediate, and final solid materials as well as the collection of ever finer particulate wastes, circumstances of undesired build-up, lumping, and other troublesome aggregations have increased tremendously. During that same period of time, a better understanding of the agglomeration phenomenon has led to many beneficial applications of desired and controlled size enlargement to obtain an increasing number of benefits (Chapter 6, Tab. 6.1).

Therefore, in planning the contents of this book, in spite of its growing importance, just one chapter was allocated to deal with the undesired occurrences of agglomeration and the most common methods to avoid or at least lessen its effect.

For the presentation of desirable size enlargement processes in industry, the entire field was sub-divided into a number of segments. In each, the most important application(s) is (are) being presented in considerable detail as examples, describing the history, development, and present state of the technique(s). From this, knowledge and guidance may be gleaned for interdisciplinary use during the evaluation of similar applications in other industries and/or for different materials.

In some areas, the author has decided to describe or indicate in varying detail some less well known, normally more partial methods for size enlargement by agglomeration. These were selected to broaden understanding of the possibilities for beneficially applying the phenomenon for obtaining specific product characteristics and may suggest the use of similar approaches for other cases.

2
Agglomeration as a Generic, Independent, and Interdisciplinary Field of Science

Agglomeration, the sticking together of particulate matter, is a natural phenomenon and is as old as the existence of solids. Originally, it happened during the development of soil, stone, and rock formations. Later, unwanted agglomeration occurred during handling and storage of particulate matter by humans, especially when hygroscopic and/or soluble materials (such as salt) set into lumps or large more-or-less solidified masses. In the animal world agglomeration was and is used to develop protective coatings, to build nests, and to provide a nourishing and protective environment for the offspring (e.g., by the legendary *Scarabaeus Sacer*, the dung beetle, Fig. 2.1, the mascot of this agglomeration expert).

"Size enlargement by agglomeration" is the generic term for the operation in Mechanical Process Engineering that is characterized by the descriptions "combination with change in particle size" (Fig. 2.2). It is distinguished from the more general "size enlargement" such that particle growth occurring, for example, during crystallization

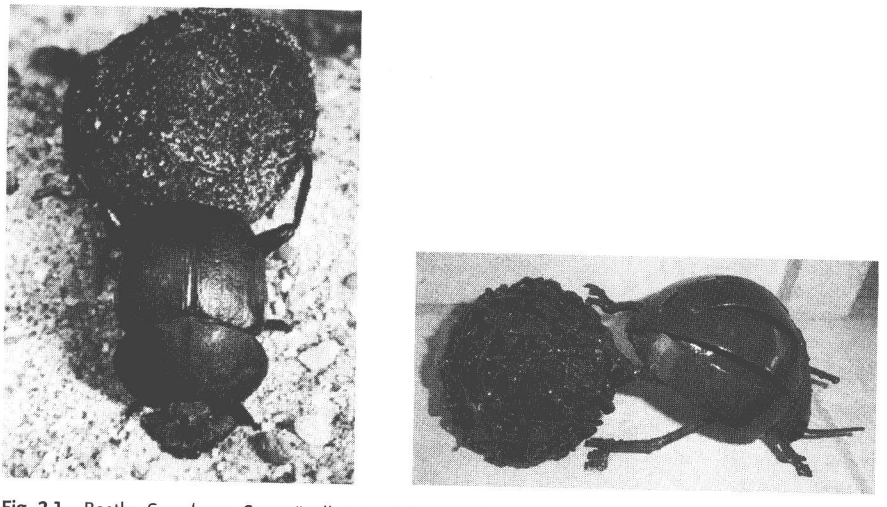

Fig. 2.1 Beetle, *Scarabaeus Sacer*, "pelletizing" dung and an artist's impression of this animal's procedure

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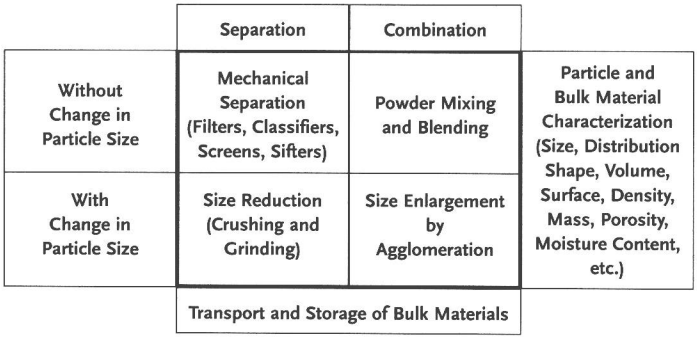

Fig. 2.2 Operations of Mechanical Process Technology and associated techniques

or the production of particulate solids by melt solidification are not part of this operation [B.97].

Most probably, humans first used agglomeration during the making of bread. The technology of bread making combines all components of a complex agglomeration process including preparation of solid feed particles by milling (adjustment of particle size and activation of the inherent binder, starch), mixing of particulate solids with additional binder(s), forming the mass into a green agglomerate, and a post-treatment (curing = baking = heating and cooling) to provide strength and texture. Very early it was also found that the porosity and, thus, the ease and enjoyment of consumption of the final product could be modified (increased) by making use of gases that are produced during fermentation (initiated by sourdough or yeast) and result in bubbles in the green mass. These voids are stabilized by strengthening the bread during post-treatment (baking).

For the construction of permanent shelter, humans may have observed the activities of animals that formed nests and protective "walls" from wet clay, which hardened during drying. By copying this behavior, wet clay, which was soon reinforced and made more water resistant by mixing-in straw or other fibrous material, was filled into a framework of wood branches and let harden during natural drying. To make building activities independent of the location of stone quarries, during prehistoric times bricks were already produced from clay and sand when rock was not easily available, thus allowing the development of villages and, during the 4th millennium BC in Mesopotamia, cities (e.g., Uruk) with large brick structures.

By experience, humans learned that certain natural materials helped cure specific illnesses. Minerals as well as dried animal and plant matter were ground to powder and formulated to yield medicines. Since powders cannot be easily consumed orally, natural binders, such as honey which, incidentally, also masked the unpleasant taste of some of the medicinal components, were mixed with the powder and the resulting plastic mass was rolled by hand into little balls (pills). The sticky binder(s) caused pills to adhere to each other; therefore, it was soon found that coating the pills by rolling them in flour or pollen solved this problem.

These three well-known ancient agglomeration techniques were used with little change through the ages of human history. Many other, lesser known or more recent processes could be added and some will be mentioned later in the appropriate sections of this book. At this point, the short review and the examples relating to three major modern industries (food, building materials, and health products) were selected to show that humans always lived with and used agglomeration. As a result, technologies for the mechanical processing of solids were considered normal activities, which, with the beginning of industrialization in the 18th and 19th centuries, were merely mechanized by simulating what was done manually before. During these early modernization efforts it was not considered necessary to question the fundamentals of the processes and improvements were based on empirical developments.

Until very recently, agglomeration technologies, as all the other unit operations and associated techniques of Mechanical Process Technology (Fig. 2.2), had been developed independently by the particular industries in which they were applied. Because the process requirements are very different in such unlike industries handling, for example, coal and ores on one hand or food and pharmaceuticals on the other, no interdisciplinary contact and exchange of information took place. In fact, although agglomeration techniques developed along similar lines, application related theories were defined, which were derived from investigations of specific requirements. Solutions of such work were not universally useable and the terminology was often incomprehensible to the agglomeration expert of another industry.

Agglomeration as a science began when an effort was made to interdisciplinarily combine the extensive knowledge that had been accumulated during sometimes hundreds of years in specific fields of human activities. It was found that, in all the different environments, agglomeration methods follow the same fundamentals, apply the same rules, and use essentially the same equipment and systems if looked at from a basic interdisciplinary point of view.

Although these facts become more and more known, there is still the understandable preconceived notion of, for example, somebody working in an ultra-clean environment, such as pharmaceutical, food, or electronic industries, that developments, expertise, and know-how gained in the dirty plants of, for example, minerals or metals production and processing, can not be considered as generally valid information and, therefore, may not be applied for the solution of a clean problem, and vice versa. In dirty industries, a typical concern is that the often much more deeply and completely investigated technologies that originate in clean industries can not be applied because the production capacities are too small, the process may be batch, the equipment too complex, the execution and the materials of construction too expensive and so on.

However, as has been shown among other topics in the author's previous book [B.97], methods for the selection of the most suitable agglomeration process for a specific application are the same for all projects. While some requirements, for example in regard to equipment or system capacity or on the shape, size, and special properties of the products, may already in the pre-selection phase result in the definition of cleaner or more heavy-duty, rugged processes, the normal approach is to determine the preferred method and/or technique by considering the fundamentals as well as an

interdisciplinary pool of expertise and know-how first. Special conditions of the particular application, such as, for example, hot and dusty large volume processing, or the opposite, clean, small capacity operation with cGMP (current good manufacturing practice) and CIP (cleaning in place) capabilities, are special design criteria that can be added to most of the systems later during the engineering phase.

Nevertheless, for manufacturing reasons and sometimes also because of special requirements on the company's test facilities (Chapter 9.1), some vendors specialize in equipment for one or the other industry. This is a decision of convenience by the individual supplier and does not indicate the existence of a fundamentally different technology. In fact, techniques or apparatus that were developed for a specific industry can be adopted for use in areas with different environment and requirements while still maintaining the fundamental underlying principle as well as the general machinery and process. Examples are crushing with high pressure roller presses, flaking, instantizing, spheronizing, and agglomeration with spray dryers.

Further Reading

For further reading the following books are recommended: B.3, **B.4**, B.6, B.7, B.8, **B.12, B.13a through e**, **B.15**, **B.16**, **B.17**, **B.19**, **B.21**, **B.22**, **B.24**, **B.26**, **B.35**, **B.36**, **B.40**, **B.41**, **B.48**, **B.49**, B.51, **B.52**, **B.55**, **B.56**, B.58, B.63, **B.66**, **B.67**, **B.68**, **B.70**, B.72, **B.73**, B.82, B.83, **B.89**, **B.93**, **B.94**, **B.97**, B.99, B.106 (Chapter 13.1). Books mainly devoted to the subject matter are printed bold.