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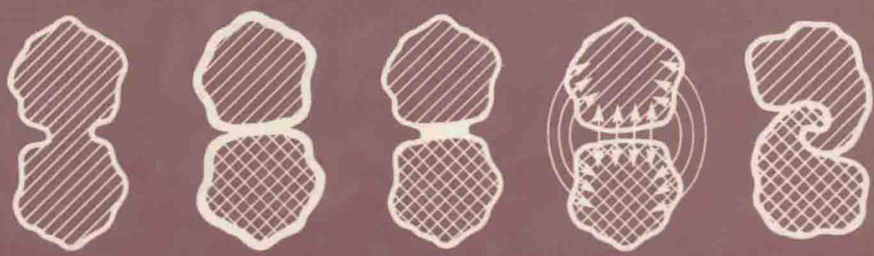
# SIZE ENLARGEMENT BY AGGLOMERATION



Wolfgang Pietsch

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WOLFGANG PIETSCH



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# Dedication

I would like to dedicate this book to my wife Hannelore who, for almost thirty years, has suffered through the tedious process of creating more than 100 publications including an earlier book entitled *Roll Pressing* and many additional technical presentations. During these years she has prepared most of the drafts and in many cases also the camera-ready final manuscripts.

Conceptual work on this book began eight years ago. Throughout its progress my wife has participated by processing and editing the entire text. We have both spent countless hours of our 'leisure time' working on the project. My wife's understanding and active support, particularly during the last two years, did not allow tensions to create insurmountable problems so that, in the end, the work was finished and the book could be published.

Once again, thank you Hannelore!

Wolfgang Pietsch

Charlotte, NC, USA,
Fall 1990

# Preface

Agglomeration as a *basic physical effect* must have existed since particulate solids were first formed on Earth (e.g. formation of sand stone and other rock formations). Agglomeration as a *phenomenon* must have been observed (e.g. caking and build-up during handling of particulate matter) and has been used by higher developed organisms and later by humans since prehistoric times (e.g. building of protective coats and nests or forming of artificial stones from sand and clay). Agglomeration as a *'tool' to improve powder characteristics* was used by ancient doctors (e.g. for making medicine pills) and builders (clay brick).

In spite of this long 'history', agglomeration as a *technology* is only about 150 years old today (excluding small scale pharmaceutical and some little known ancient, mostly Chinese, applications and brick making). It started around the middle of the nineteenth century as a method to recover and use coal fines.

Agglomeration as a *science and unit operation* is very young. It began in the 1950s with the definition of the binding mechanisms of agglomeration. At approximately that period, the first professional meetings exclusively devoted to the science and technology of agglomeration were also organized (International Briquetting Association, IBA, 1949, which is today the Institute for Briquetting and Agglomeration; International Symposium Agglomeration, 1962). Since that time, i.e. during the past approximately 40 years, agglomeration science, technology, and use have experienced rapid growth without finding corresponding awareness at institutions of higher learning and the technical or process engineering communities.

Therefore, it was the author's intent to cover—for the first time in a textbook on agglomeration—the fundamentals in considerable detail and to introduce the multitude of agglomeration techniques as well as applications that have been developed during the past 100 years and, more specifically, during the most recent four to five decades. In Chapter 4 (Industrial Size Enlargement Equipment and Processes) as well as Chapter 5 ([Some Selected] Industrial Applications of Agglomeration) pressure agglomeration and, explicitly, roller presses have been covered in particular detail because of the author's past and present involvement as an expert in this area.

Even though the technology of size enlargement by agglomeration is young and the science is not yet taught at the majority of engineering colleges and universities, the field related to this unit operation has grown so rapidly that the book does not claim to be complete and current on all recent developments. Particularly the section on Applications (Chapter 5) does not cover the entire domain. It is the author's intention to periodically update the information by publishing revised editions of this book, thus giving credit to the growing importance of *Size Enlargement by Agglomeration*.

# Disclaimer

# Contents

# 1 Introduction

## 1.1 Definitions

### 1.1.1 Subdivisions of Process Technology

*Process technology* is concerned with the transformation of matter in the widest sense, i.e. it deals with the changes of materials according to nature, quality, and composition. Transformation of matter occurs generally in several steps and with the addition or release of energy. It is characterized by changes in state and/or transport phenomena.

Figure 1 is the schematic representation of those changes that control different tasks of process technology. According to this presentation which was developed by Rumpf[1] three fields can be distinguished. In *chemical process technology* the transformations are controlled by chemical reactions and in *thermal process technology* transformations and exchange phenomena occur between thermodynamically defined phases. In both cases the actual conditions are determined by equilibria, which follow the laws of thermodynamics, and by system parameters such as pressure, temperature, composition, etc. Transformations of *mechanical process technology* are characterized by changes in the state of disperse systems and of mixtures consisting of particulate matter and continuous fluid phases. The final state depends on the motions and forces exerted upon the elements of the system.

In spite of these seemingly well-defined distinctions the different fields of process technology are interconnected. For example, in addition to the individual importance of mechanical processes for the generation of specific product characteristics, mechanical process technology is often also used during the performance of chemical or thermal processes. In those cases they precede the chemical or thermal process steps or are directly linked to them; often, utilization of the change in state takes place only during application of the product by the consumer. For example, different product forms of sugar, i.e. agglomerated and cubed, granular, or powdered, offer different applicability and/or solubility and therefore characteristic uses.

### 1.1.2 The Concept of Disperse Systems in Mechanical Process Engineering

During most processes of mechanical process technology, the solid matter treated is divided into *particles* of different sizes and shapes. According to Figure 2 the size range covers six to eight orders of magnitude.

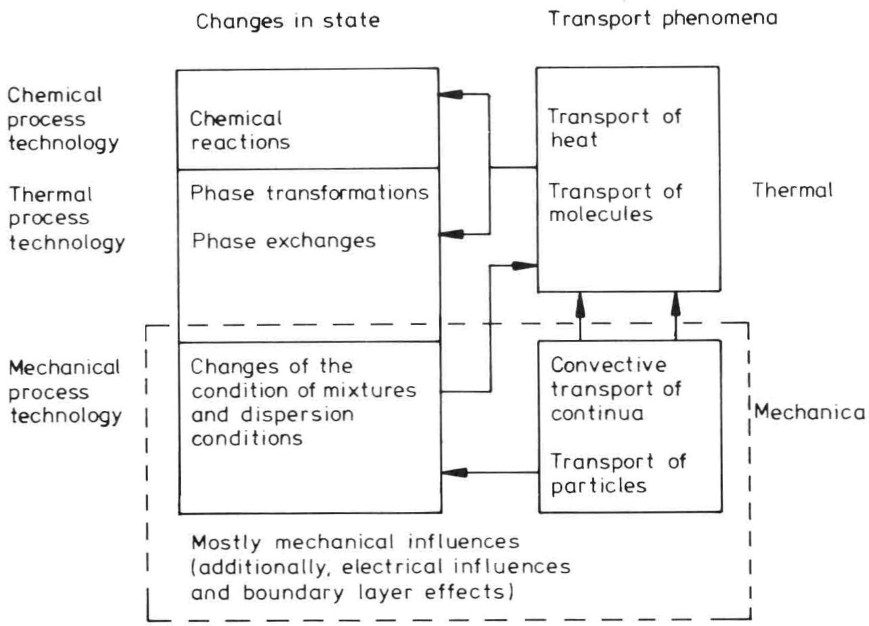


**Figure 1.** Changes in state and transport phenomena of process technology according to Rumpf[1]

*Disperse systems* consist normally of two or more phases in which the continuous phases are intermixed. If, in a continuous phase (the *dispersion medium*), the elements of the *disperse matter* are embedded such that they can be individually distinguished, the system is called *discretely disperse*. A coherent disperse phase, which may also consist of well-defined elements adhering to or intermixed with each other, is called *compact disperse*.

The discrete elements are called *particles*; their sizes range from large pieces with linear dimensions of several meters through millimeter-sized grains to submicrometer dust. Therefore, the descriptive term *particle technology* is often applied to large areas of mechanical process technology.

### 1.1.3 Classification of Mechanical Process Engineering

Beginning in 1957 by H. Rumpf, Professor at and Director of the Institute of Mechanical Process Engineering at the Technical University (TH) of Karlsruhe, West Germany, and later by others, mechanical process technology was opened to scientific treatment by introducing definitions and classifications.

Technological processes can be subdivided into *unit operations*, which—independent of material and process—follow the same scientific law and can be carried out in technically similar equipment. A simple matrix (Figure 3) can be used to explain the relationships between the unit operations of mechanical process engineering. The four major operations can be described by the events

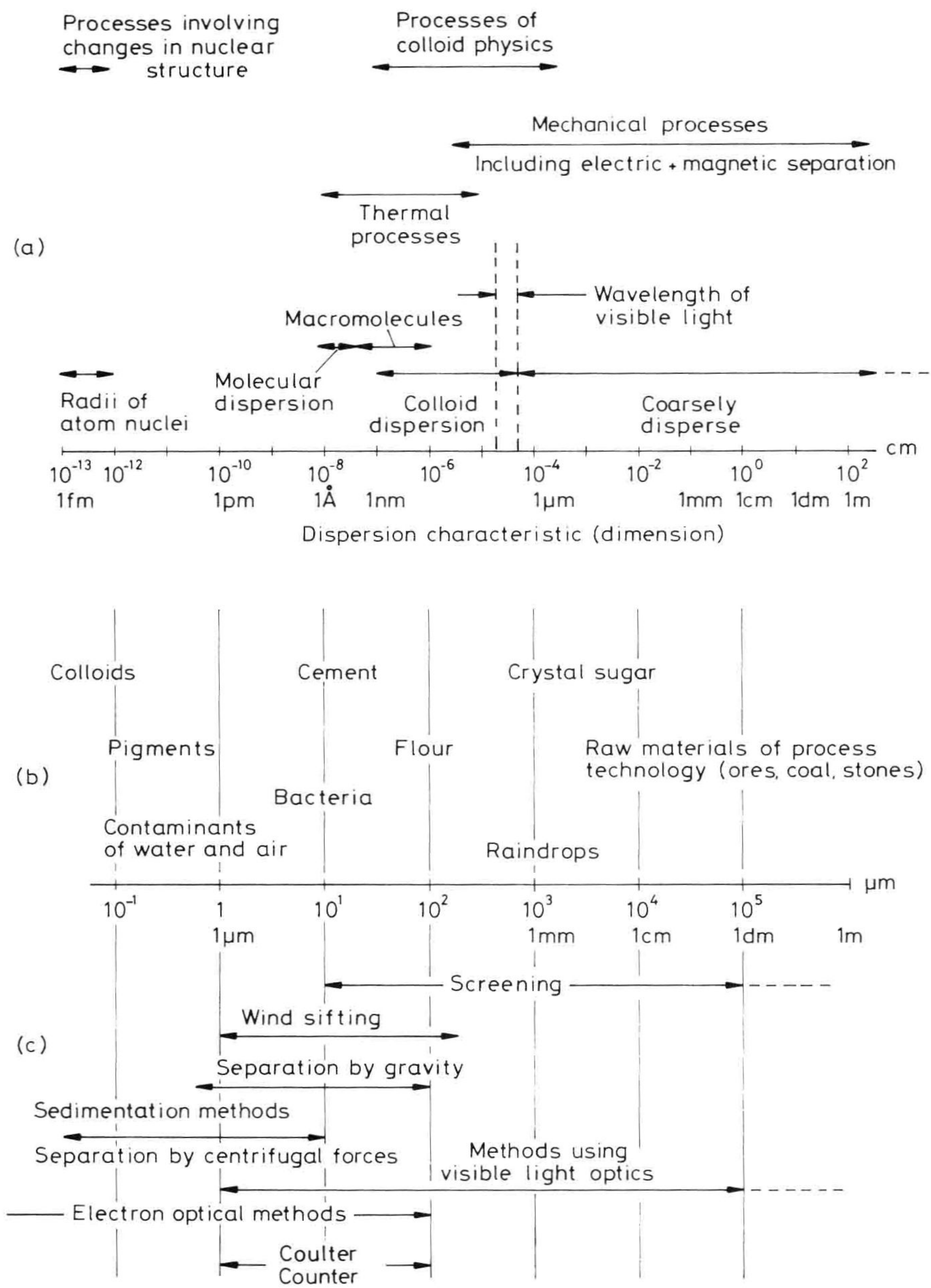


**Figure 2.** Characteristics of disperse systems. (a) Processes, (b) materials, (c) methods of analysis

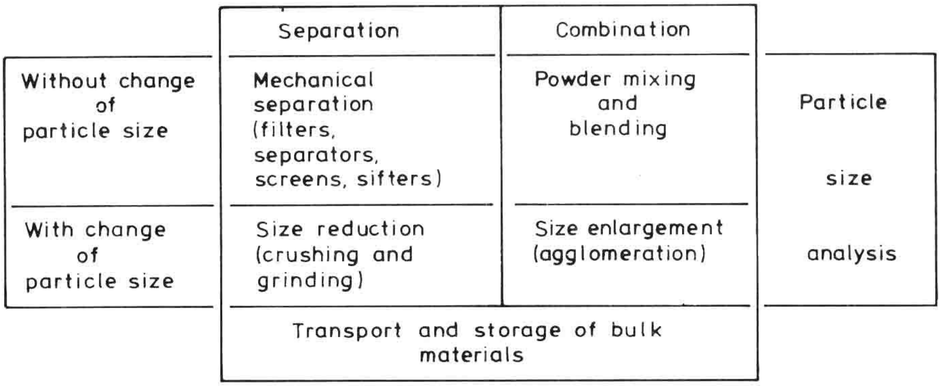


**Figure 3.** Unit operations and related fields of mechanical process technology according to Rumpf[1]

'separation' and 'combination' as well as the resulting change in particle size of the participating solid matter.

During *size reduction* (e.g. crushing and grinding) the dimensions of particles are changed by the forces acting upon the system. *Mechanical separation* occurs without change in size; particles are removed from fluids (e.g. in filters or separators) or separated according to particle size and/or shape (e.g. on screens or in sifters). In *solids mixing* the distribution of particles relative to each other is modified without changing their individual size and shape. During *size enlargement* (agglomeration) adhesion forces become effective, resulting in increased particle size which is often also combined with a change in product shape.

This basic classification is complemented by *transportation* methods because materials must be fed to or discharged from process steps and *storage* may be necessary before, between, and/or after processing. *Particle size analysis* quantitatively determines the distribution of particle sizes in the disperse system, a task of utmost importance since particle size, distribution, particle shape, and particle concentration decisively influence the behavior of a particulate system.

## 1.2 Properties of Fine Particles

Table 1 shows some important characteristics of materials and disperse systems which depend on particle size.[1]

For single particles the characteristics describing quality usually improve as the particle size decreases. In particular the chemical, physical, and mineralogical homogeneity increases. Herewith, those characteristics that critically depend on uniformity of structure improve also. For example, all real solids have an imperfect structure; during loading stress concentrations occur at the structural defects which may cause breakage. With decreasing particle size the probability for imperfections diminishes, resulting in a reduced risk of breakage and therefore higher strength. At the same time, the possibility for irreversible

**Table 1.** Influence of particle size on some important characteristics of materials[1]

| A. Characteristics of single particle | | ... with decreasing particle size |
|---|---|---|
| A.1. | Homogeneity | Increasing ... |
| A.2. | Elastic–plastic behavior | Increased ductility ... |
| A.3. (a) | Probability of breakage | Decreasing ... |
| (b) | Strength | Increasing ... |
| A.4. (a) | Wear | Decreasing ... |
| (b) | Resistance to mechanical surface treatment | Increasing ... |
| A.5. | Characteristics resulting from the competition between volume and surface related forces | Increasing ... |
| A.6. | Vapor pressure, solubility, reactivity | Increasing ... |
| A.7. | Optical characteristics | Increasing ... |
| **B. Characteristics of particle collectives** | | **... with decreasing particle size** |
| B.1. | Bulk density (space-filling behavior) | Decreasing ... |
| B.2. | Rheologic behavior | Increasing ... |
| B.3. | Flow characteristics, flowability (of particles) | Decreasing ... |
| B.4. | Mixing characteristics | First increasing then decreasing ... |
| B.5. | Separation behavior | Decreasing ... |
| B.6. | Wettability | Decreasing ... |
| B.7. | Capillary pressure (system: solid/liquid) | Increasing ... |
| B.8. | Agglomerate strength | Increasing ... |
| B.9. | Fluid flow characteristics | |
| (a) | Flow through pores (in particle collectives) | Decreasing ... |
| (b) | Resistance to fluid flow | Increasing ... |
| (c) | Ease of fluidization | First increasing then decreasing ... |
| B.10. | Thermal characteristics | Increasing ... |
| B.11. | Ignition behavior and explosiveness | Increasing ... |
| B.12. | Taste standards | Increasing ... |
| B.13. | Optical characteristics | Extinction, diffuse reflection ... |

deformation increases with decreasing particle size. For example, limestone or quartz with particle sizes of less than 10 and 3 $\mu$m, respectively, deform plastically before breakage begins.

On the other hand, problems associated with mechanical processing and handling of particle systems increase with decreasing particle size.

## 1.3 Desired and Undesired Agglomeration[2,3]

During production and processing of solid matter in disperse systems, adhesion phenomena become more and more important with decreasing particle size, causing aggregation, agglomeration, coating, and caking. The critical particle

**Table 2.** Review of the occurrence of desired and undesired agglomeration phenomena in mechanical process engineering

| Unit operation | Process | Agglomeration | |
|---|---|---|---|
| | | Undesirable | Desirable |
| Comminution | Dry grinding | + | – |
| | Wet grinding | + | – |
| Separation | Screening, sieving | + | – |
| | Classifying<br>Sorting | + | (+) |
| | Flotation | + | (+) |
| | Dust precipitation | (–) | + |
| | Clarification, thickening | (–) | + |
| | Particle size analysis | + + | – |
| Mixing | Dry mixing | + | – |
| | Wet mixing | + | + |
| | Stirring | + | (+) |
| | Suspending<br>Dispersing | + | (+) |
| | Fluidized bed | + | + |
| Particle size enlargement | Agglomerating<br>Briquetting<br>Tabletting<br>Granulating<br>Pelletizing<br>Pelleting<br>Sintering | (+) | + + |
| Conveying | Vibratory conveying | + | – |
| | Pneumatic conveying | + | – |
| Storage | Silos, hoppers | + | – |
| | Stockpile | + | – |
| Batching<br>Metering | | + | – |
| Drying | | + | + |

Explanations:
+ Yes (+) Sometimes yes
No (–) Sometimes no

size is approximately 100 $\mu$m, but it is also possible that much coarser particulate matter can be affected if a sufficiently large fraction of fine particles is present or if specific binding mechanisms become effective.

Adhesion of finely divided material takes place during all operations of mechanical process engineering and can be either desired or undesired. Table 2 provides a compendium.