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HANDBOOK OF POWDER TECHNOLOGY

Volume 5

L. SVAROVSKY

SOLID — LIQUID SEPARATION PROCESSES AND TECHNOLOGY

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SOLID–LIQUID SEPARATION PROCESSES AND TECHNOLOGY

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HANDBOOK OF POWDER TECHNOLOGY

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The Handbook presents, in convenient form, existing knowledge in all specialized areas of Powder Technology.

Information that can be used for the design of industrial processes involving the production, handling and processing of particulate materials so far did not exist in a form in which it is readily accessible to design engineers. Scientists responsible for characterizing particulate materials, specifying the requirements of industrial processes, operating plants, or setting up quality-control tests all have similar problems in their fact-finding missions through the scattered and scanty literature. The aim of this handbook is to remedy this deficiency by providing a series of thematic volumes on various aspects of powder technology. Each volume is written as a monograph and can be used independently of other volumes.

Emphasis is placed on setting out the basic concepts of the subject and discussing their applications to the design, selection and operation of equipment of an industrial scale. To ensure timely publication, each volume will be published as soon as the material has been delivered by the authors.

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Vol. 5 Solid-Liquid Separation Processes and Technology (L. Svarovsky)

(For further information on Volumes 1–4, see p. 146 of this volume.)

PREFACE

It has been my ambition to produce a comprehensive and balanced account of the technology available for solid–liquid separation. Having practiced University teaching for the last twenty years, I found it most natural to write the book as a teaching text. The emphasis, however, has been on the description of basic principles, processes and technology, rather than underlying theory.

Directing and teaching post-experience short courses for industry has undoubtedly been the main inspiration for this book. The thousand or so participants who have so far attended my 40 short courses on solid–fluid separation have been a strong influence in keeping my feet firmly on the ground. Although neglected for a long time by chemical engineers, the subject of solid–liquid separation has seen a revival in the last few years. This is reflected in the high attendance of the above-mentioned short courses, and of symposia and conferences, as well as in the number and quality of the books that have recently appeared on the market.

The dramatic increase in the attention given to this subject by industry on both sides of the Atlantic Ocean is attributed primarily to the introduction of tighter legislation on water pollution, to the rising costs of fresh water and energy, and also to the increased recognition of the subject by the chemical engineering institutions.

As a consequence, the technology of solid–liquid separation has also experienced a marked improvement, and several new additions and developments can be clearly identified. Examples of such new developments include advances in chemical pretreatment, increased utilization of mechanical expression, revival and further development of ultrafiltration, cross-flow filtration, electro-filtration, dissolved air flotation and magnetic separation. In parallel with the development of the hardware, advances have also been made in the understanding of the basic mechanisms, thus closing the gap between theory and practice. This has been very much the case in cake filtration, gravity thickening, pre-treatment, and cake washing and dewatering.

The purpose of this book is to give an up-to-date, balanced and exhaustive account of the available technology in solid–liquid separation, with emphasis on the principles, design, and basic engineering concepts and some reference to the basic tests and procedures for scale-up. The intention is to remain as non-commercial as possible, with little reference to manufacturers except when the equipment is very unique. Much of the information given in the book is general knowledge, and the typical performance figures quoted are only of general guidance. The reader will be aware of the pitfalls of taking such generalized statements too literally.

References are used sparingly because, having taught the subject for so long, I am no longer sure of the original sources of the now general information available. Specific references are given, however, when I considered that the reader might want to study the matter further or when the point under discussion is new and still developing rapidly (hence the increased use of references in Chapter 6).

The book is intended for practicing engineers, as well as for any newcomers to the field or students. Areas of application include the chemical, petrochemical, food, nuclear fuel, pharmaceutical, cosmetic, waste water and potable water treatment, mining, mineral processing, metallurgy, paper and pulp, textile and agricultural industries.

The contents of the book derive very much from my contacts with other people. Many have shared their knowledge and experience with me, whether they were people I was consulting for, course participants or course lecturers; although too numerous to mention by name here, they all deserve an acknowledgement. Another important group of people are the many students, both undergraduate and postgraduate, who for over a decade have worked with me at Bradford University on various projects related to particle separation. My thanks are also due to the bodies who sponsor the short courses I direct in Britain, continental Europe and the USA: The Institution of Chemical Engineers, the British Hydromechanics Research Association and the Center for Professional Advancement.

I am very grateful to my colleague and Editor of this series, Dr. J.C. Williams, for his constructive comments regarding both the content and the presentation of the manuscript.

Last but not least, I am grateful to my family, who patiently suffered the inevitable reduction in my attention in the course of preparation of this book.

LADISLAV SVAROVSKY

To my wife Jitka

CONTENTS

Chapter 1

INTRODUCTION

Most of the process industries in which particulate suspensions are handled use some form of solid–liquid separation.

As the name suggests, solid–liquid separation is the separation of two phases, solid and liquid, from a mixture. The technology for carrying out this process is often referred to as "mechanical separation" because the separation is accomplished by purely physical means. This does not preclude chemical or thermal pre-treatment which is increasingly used to enhance the separation that follows. Although some slurries separate perfectly well without chemical conditioning, most pulps of a widely varying nature can benefit from pre-treatment, whether the separation is by sedimentation, filtration or flotation. The chemical pre-treatment is considered in Chapter 2.

There are many primary and secondary properties of the suspensions which affect the function of the available equipment and some knowledge of the fundamentals is necessary for the understanding, selection, scale-up and efficient operation of the equipment. The available theory is still lagging behind practice, but it is useful for at least qualitative assessments. Chapter 2 on "Fundamentals" is concerned only with four major areas and the treatment is only explanatory, as pertinent to the scope of this book.

As in other unit operations in chemical engineering, such as mass or heat transfer, the solid–liquid separation process can never be carried to completion (except by thermal drying). There may be some solids leaving with the liquid in the overflow stream and there will certainly be some liquid entrained with the solids leaving through the underflow. One of the important concerns in this subject is therefore the question how complete is the separation achieved with a given piece of equipment under a given set of operating conditions. For doing this, there has to be a common, well defined way of assessing the efficiency of separation. Chapter 3 is devoted to this problem.

1.1 Solids washing

There are several processes in and aspects of solid–liquid separation which due to their special role require particular attention. One such process is washing of the solids. This process is used to replace the mother liquor in the solids stream, the latter being usually in cake form, with a wash liquid. The growing importance of this process arises from the demands for increasing purity of the products, combined with the increasingly poorer raw materials available. Washing may often represent a dominant portion of the installation cost because it is usually multi-staged.

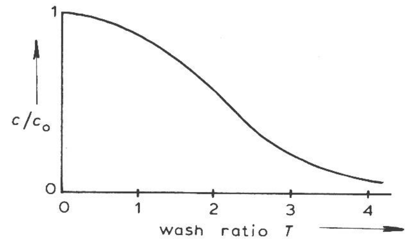

Fig. 1.1 A typical cake washing curve.

The quality of washing is characterised by the washing curve as shown in Figure 1.1, which plots the ratio of the instantaneous to the initial mother liquor concentration in the cake against the quantity of the washing liquid used. The quantity of the wash liquid is usually expressed as the ratio of the volume of liquid used to the volume of the voids in the particle bed; this ratio is known as the "wash ratio". Ideally, the washing curve should be a step function at one void volume, which would indicate complete displacement of the mother liquor but, in practice, the amount of mother liquor remaining in the bed gradually declines , approaching, but never reaching zero. The knowledge of the washing curve is important for equipment design and scale-up. The suitability of different types of equipment for solid–liquid separation to washing varies widely and is mentioned in the appropriate sections. Several models exist to describe and predict washing performance from a minimum of experimental measurements. Washing can be co-current or counter-current, it often has to be done in several stages, and it is advantageous to enhance it by compression. In some cases of high specific resistance of the cake to flow, or of cake cracking, washing by reslurrying of the cake may be advantageous.

1.2 Solids dewatering

Dewatering is another process identified as a separate unit in solid–liquid separation and its aim is simply to reduce the moisture content of filter cake. It is achieved either by mechanical compression or by air displacement under vacuum, pressure or by drainage in a gravitational or centrifugal system. Dewatering of cake is enhanced by the addition of dewatering aids to the suspensions, in the form of surfactants which reduce surface tension.

In dewatering by mechanical compression, the necessary prerequisite is the compressibility of the cake and this is usually expressed by an empirical exponential equation which relates cake voidage to applied pressure. In dewatering by air (or other gas) displacement the important issues are the threshold pressure which has to be exceeded in order that air may enter the filter cake, the irreducible saturation level which gives the least moisture content achievable by air displacement, and finally the kinetic dewatering characteristics. Figure 1.2 gives an example of a typical capillary pressure curve from which the threshold pressure and irreducible saturation can be identified. Similarly, in dewatering by gravity or centrifugal action, the irreducible

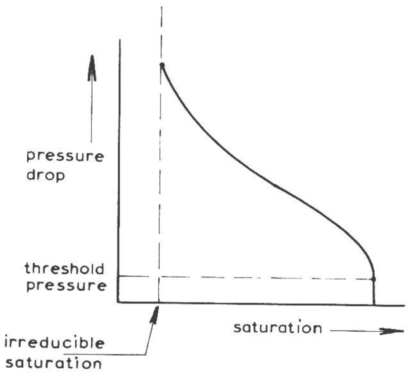

Fig. 1.2 A typical capillary pressure curve in air displacement dewatering.

saturation and kinetic dewatering characteristics have to be known for effective equipment design and scale-up.

1.3 Addition of inert filter aids

Filter aids are rigid, porous and highly permeable powders which are added to the feed suspensions to extend the applicability of surface filtration. Very dilute or very fine and slimy suspensions are normally too difficult to filter by cake filtration due to fast pressure build-up and blinding of the medium but the addition of filter aids can reduce the severity of these problems. They can be used in either or both of the following modes of operation:

- to form a pre-coat (which then acts as a filter medium) on a coarse support material called a septum, or
- to be mixed with the feed suspension as "body feed" in order to increase the permeability of the resulting cake.

In the pre-coat mode, filter aids allow filtration of very fine or compressible solids from suspensions of 5% or higher solids concentration on a "rotary drum pre-coat filter". This modification of the rotary drum vacuum filter uses an advancing knife to skim off the separated solids and the uppermost layer of the thick pre-coat continuously, until the whole of the pre-coat is removed and a new layer has to be applied. This makes it possible to discharge very thin cakes as well as that part of the pre-coat which has been penetrated into by the solids and partially blinded.

In the pre-coat and body feed modes, filter aids allow application of surface filtration to clarification of liquids, i.e. filtration of very dilute suspensions of less than 0.1% by volume, such as those normally treated by deep bed filters or centrifugal clarifiers. Filter aids are used in this mode mostly with pressure filters. A pre-coat is first formed by passing through the filter a suspension of the filter aid. This is followed by filtration of the feed liquid, which may have the filter aid mixed with it as "body feed" in order to improve the permeability of the resulting cake. The proportion of the filter aid to be added as body feed is of the same order as the amount of contaminant solids in the feed liquid and this of course limits the application of such systems to low concentrations. Recovery and regeneration of filter aids from the cakes is normally not practised except in a few very large installations where it might become economical.

Materials suitable as filter aids include diatomaceous earth, expanded perilitic rock, asbestos, cellulose, non-activated carbon, ashes, ground chalk or mixtures of those materials. The amount of body feed is subject to optimization and the criterion for the optimization depends on the purpose of the filtration. Maximum yield of filtrate per unit mass of filter aid is probably the most common criterion (see an example in Figure 1.3), but longest cycle, fastest flow, or maximum utilization of cake space are other criteria which each require a different rate of body feed addition. The tests to be carried out for such optimization normally use laboratory or pilot scale filters and have to include variation of the filtration parameters such as pressure or cake thickness in the optimization.

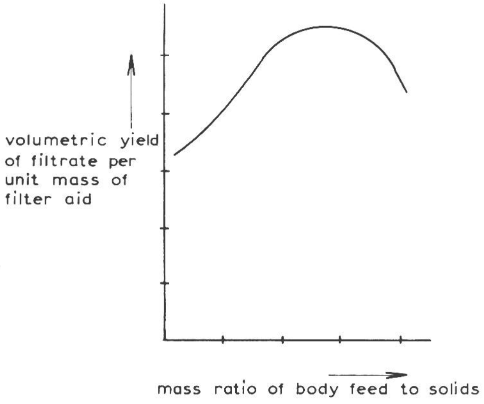

Fig. 1.3 Optimization of body feed for maximum filtrate yield.

1.4 Solid–solid separation

Another special operation closely married to solid–liquid separation is solid–solid separation by particle size, solids density or affinity to water. The purpose here is to use the solid–liquid separation processes to remove only the coarse fraction of the solids or only one mineral from a mixture.

Taking first the separation by particle size, this is clearly based on the size dependent nature of some solid–liquid separation principles and equipment, such as hydrocyclones or sedimenting centrifuges. Solids are "classified" by the separation process and the feed is either split into coarse or fine fractions (with the fine fraction usually remaining in suspension) or only a tail removed from either end of the size distribution (de-gritting or de-sliming). Even in cases when solids classification is not required, it may still be desirable before the solid–liquid separation stage in order that the material in each size range may be treated by the type of equipment best suited to it.

The grade efficiency concept is used extensively here, with the major concern about the steepness of the curve because it determines the amount of misplaced material (fines in the coarse product and coarse particles in the fine product).

Gravity sedimentation equipment, hydrocyclones, sedimenting centrifuges or flotation cells have also been extensively used in mineral processing for separation of minerals according to density or affinity to water. Although strictly not within the scope of this book, this application is also briefly discussed in the appropriate sections on equipment.

1.5 Classification of equipment and principles

Figure 1.4 gives the general classification of equipment and principles of solid–liquid separation. There are two separate classes which differ in the way the particles are collected.

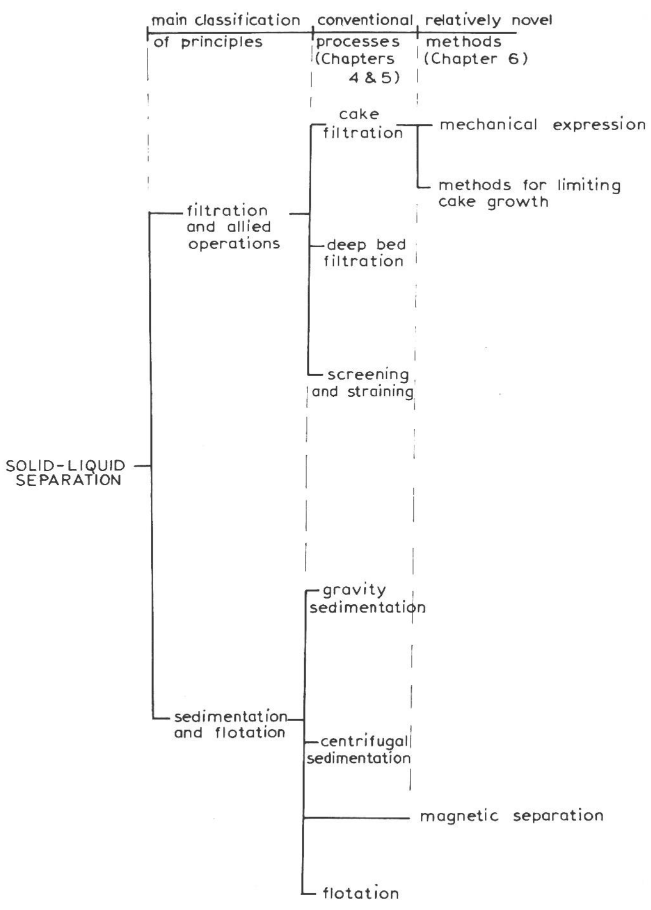

Fig. 1.4 Classification of solid–liquid separation processes.