IChemE
INSTITUTION OF CHEMICAL ENGINEERS

Solid|Liquid SEPARATION

Equipment Selection and Process Design

Steve Tarleton and Richard Wakeman

BH

Solid/Liquid Separation: Equipment Selection and Process Design

E. S. Tarleton

Senior Lecturer, Department of Chemical Engineering, Loughborough University, UK

R. J. Wakeman

Professor, Department of Chemical Engineering, Loughborough University, UK
Consultant Chemical Engineer

IChemE
INSTITUTION OF CHEMICAL ENGINEERS

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK • OXFORD
PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
BUTTERWORTH-HEINEMANN IS AN IMPRINT OF ELSEVIER

BH

Butterworth-Heinemann is an imprint of Elsevier
Linacre House, Jordan hill, Oxford, OX2 8DP
30 Corporate Drive, Suite 400, Burlington, MA 01803

First edition 2007

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN–13: 978-1-85-617421-3
ISBN–10: 1-85-617421-2

For information on all Butterworth-Heinemann publications visit our website at books.elsevier.com

Printed and bound in Great Britain

07 08 09 10 11 10 9 8 7 6 5 4 3 2 1

Solid/Liquid Separation:

Equipment Selection and Process Design

Preface

The purpose of this book is to inform engineers and separations technologists about the available equipment options for solid/liquid separation, to put these into classifications so that informed equipment selections can be made for a particular separations problem, and to present applicable models so that meaningful design and simulation calculations can be carried out. Within this framework, the role of computer software is elucidated and through the use of numerous worked examples the nature and significance of calculations that can be undertaken are shown.

Many previous texts have attempted to catalogue the range of equipment used in solid/liquid separation systems, and much of their content is devoted to descriptions of equipment types and their operational characteristics from a wholly empirical and pragmatic point of view. In general these texts do not take advantage of the models available to advance the design process and facilitate simulation, and therefore fail to offer the engineer the cost savings that can be made through simulation. Other texts have dealt with the theory and equations of filtration, sometimes with guiding examples. The link of theory to the design process is not developed in these texts, limiting their usefulness from a practical viewpoint. While a total theoretical description of filtration may not be possible currently, scientifically based data are available for many of the processes that can be modelled. When these models are used in conjunction with the heuristics that have evolved from practice, the results are a powerful set of modelling tools capable of predicting filter performance from a minimum of experimental data.

Filtration and separation technology contains numerous heuristics that have evolved through experience. A majority of process engineers need to possess wide-ranging knowledge covering many unit operations, but they rarely have the opportunity to gain in-depth specialist knowledge of filtration and

separation technology. Consequently, the large number of heuristics that have evolved in the technology can lead to confusion for the non-expert. Greater confusion results when an engineer attempts to decide which type of filter or separator is most appropriate for his/her process. In attempting to select a separator a decision has to be made from a plethora of equipment types, with competing claims from manufacturers and suppliers about their equipment capabilities.

The focus of this book is design and simulation, linking practical aspects of filter selection, data analysis and design to models that have been proven through industrial practice. The current state of knowledge is used to inter-relate the various stages of the filter cycle (i.e. cake formation, compression, deliquoring and washing) in order to provide the basis for an integrated design strategy. The approach enables an engineer to take into account the effects of upstream operations such as crystallisation or precipitation on the solid/liquid separation in question as well as the effects of the separation on downstream operations such as drying and briquetting. Tried and tested models for each stage of the filter cycle are described and related to the known operational and performance characteristics of equipment, to facilitate process calculations with a minimum of prior testing. The resulting simulations enable "what if?" questions to be answered quickly and at minimal cost, and provide detailed information about a process. The fundamentals that underpin the models are not included in this book, instead the interested reader is directed to the companion volume "Solid/Liquid Separation: Principles of Industrial Filtration, R.J. Wakeman and E.S. Tarleton, 2005 (ISBN 1-85617-419-0)". For practical aspects of equipment scale-up, including comprehensive descriptions from major manufacturers, the reader is encouraged to consult "Solid/Liquid Separation: Scale-Up of Industrial Equipment, R.J. Wakeman and E.S. Tarleton (Eds.), 2005 (ISBN 1-85617-420-4)".

We are concerned primarily here with the process filter – its selection and design, and calculations for simulation and scale-up. During preparation of the current text a conscious decision was taken to largely limit the contents to cake filtration. However, although most chapters concentrate on cake filtration, it is not possible to give a balanced account of the practical aspects of filtration without some presentation of other separation techniques. To present information to a similar depth about all of these other processes would have made the book encyclopaedic. While there is certainly a technical need for such a book, or series of books, the authors did not set out to include all solid/liquid separation techniques in the current volume. This should not be seen as an attempt to diminish the importance of depth filtration, crossflow filtration or other solid/liquid separation techniques; it is

simply a reflection of a number of the aims behind writing the book. The overall aim is to bring closer together and rationalise both practical information and fundamental knowledge. In so doing, the importance of both must be recognised and the synergy that results from a good understanding used to improve design and simulation.

With the practical problems related to equipment selection, scale-up and simulation in mind, the authors have developed and published a Windows® software package to accompany the current text. Filter Design Software® (2005) combines the calculation methods presented throughout the book and relates them to specific aspects of equipment design and performance using expert knowledge of solid/liquid separation systems and computer simulations. The process of obtaining appropriate and useful experimental data, analysing the data in a correct manner, and then using the analysed data for equipment selection, performance simulation and process modelling is brought together in the software. As well as enabling all these functions, the software is intended as a guide to the non-expert, giving information about solid/liquid separation equipment characteristics and features, together with illustrative diagrams and web access to equipment suppliers. Full details are available at www.filtrationsolutions.co.uk

In Chapter 1 of the book a comprehensive description of the wide range of available solid/liquid separation equipment is provided. The text is accompanied by numerous schematics and photographs to aid reader understanding and interpretation. Chapters 2 and 3, respectively, present details of filter media and suspension pretreatment in recognition of the crucial role that both play in the successful operation of process scale filters. Chapter 4 describes the experiments and analysis techniques that can be performed in the laboratory to provide additional information for equipment selection as well as the prerequisite information required for simulation. In Chapter 5, an industrially proven equipment selection technique is presented in conjunction with descriptions of the Filter Design Software®. Chapters 6 and 7 form a substantial portion of the book and describe in detail the methodologies that can respectively be used for the process design and simulation of batch and continuous filters. Worked examples are shown throughout to guide the reader and provide more ready access to calculation procedures.

The chosen structure makes the text useful as a handbook for both researchers and practitioners, and hopefully underlines the importance of the knowledge that both types of expert may possess. The thorough knowledge required for process design and simulation and further innovation in equipment design are likely to arise only when researchers have a good

understanding of the practical problems and practitioners possess a more "in depth" theoretical background to their processes and equipment.

Steve Tarleton and Richard Wakeman

Published in the Butterworth-Heinemann/IChemE Series

For further information about the series: books.elsevier.com/icheme

IChemE is the hub for chemical, biochemical and process engineering professionals worldwide. With offices in the UK, Australia and Malaysia, the Institution works at the heart of the process community, promoting competence and a commitment to sustainable development, advancing the discipline for the benefit of society and supporting the professional development of members. For further information visit www.icheme.org.

Contents

1 Solid/liquid separation equipment

Over the years manufacturers have developed many generic forms of solid/liquid separator. The need to compete in the marketplace and gain a competitive edge, however, has led manufacturers to develop a plethora of variants. Rather than detailing all of these variants, this chapter attempts to give a descriptive overview of the generic equipment types and the main alternatives available to the design engineer (see Figure 1.1). The advantages and disadvantages of equipment are highlighted and an effort has been made to provide quantitative values whenever possible. More guidance values for the operational parameters of filters are shown in Appendix A, while greater details of recent developments in several equipment types are presented in Wakeman and Tarleton (2005b). In addition to the more specific references given throughout this chapter, the interested reader is also referred to the texts by Dickenson (1997), Kirk-Othmer (1980), Matteson and Orr (1987), Perry and Green (1984), Purchas (1981), Purchas and Wakeman (1986), Rushton *et al* (1996), Svarovsky (1990), Schweitzer (1997) and Wills (1992).

General descriptions and typical equipment uses are shown under each main heading in addition to the solids concentration and particle size found in a typical feed. The process ratings used in the Filter Design Software® (FDS) package are described in Chapter 5. The ratings give relative values between 0 and 9 for cake dryness (and state), washing performance, liquid product clarity and crystal breakage, where 9 represents the best performance currently available; a '-' indicates that either a rating is not applicable or the equipment is not capable of performing the operation. For instance, the '1 S, 2, 5, 9' ratings shown for the circular basin thickener in Section 1.1.1 signify a wet solids discharge in the form of a slurry ('C' designates a cake and 'N' designates that solids are not recoverable), poor washing performance, near average liquid product clarity and minimal breakage of the solid product. Such representation allows potentially suitable equipment to be numerically