

SpringerBriefs in Applied Sciences and Technology

For further volumes:
<http://www.springer.com/series/8884>

Anton Alexandru Kiss

Process Intensification Technologies for Biodiesel Production

Reactive Separation Processes

 Springer

Anton Alexandru Kiss
Arnhem
The Netherlands

ISSN 2191-530X ISSN 2191-5318 (electronic)
ISBN 978-3-319-03553-6 ISBN 978-3-319-03554-3 (eBook)
DOI 10.1007/978-3-319-03554-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014930348

© The Author(s) 2014

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

*Dedicated to my loving wife for her endless
support and inspiration,
as well as to the precious memory of my
professors and mentors*

Preface

This book is among the first ones to address novel process intensification technologies, based on integrated reactive separations, for the production of biodiesel—a mixture of fatty esters. Biodiesel is a biodegradable and renewable fuel, emerging as a viable alternative to petroleum diesel. Conventional biodiesel processes still suffer from problems associated with the use of homogeneous catalysts (e.g. expensive neutralization and separation, salt waste streams) and the limitations imposed by the chemical reaction equilibrium, thus leading to severe economical and environmental penalties.

This book provides a detailed overview illustrated with several industrially relevant examples and case studies of novel reactive separation processes able to tackle the current problems and readily usable in the biodiesel production: reactive distillation, reactive absorption, reactive extraction, as well as membrane reactors and centrifugal contact separators. The integration of reaction and separation into one operating unit overcomes equilibrium limitations and provides key benefits such as reduced investment and operating costs, as well as lower plant footprint. These processes can be further enhanced by heat integration and powered by heterogeneous catalysts, to eliminate all conventional catalyst-related operations, using the raw materials and the reaction volume efficiently, while offering higher conversion and selectivity, and high energy savings compared to conventional biodiesel processes.

The focus of the book is on key aspects of these novel process intensification technologies, ranging from the working principles to conceptual design, process control, and applications. This work includes a number of novel applications relevant to industrial biodiesel and fatty esters processes, as well as results of rigorous steady-state and dynamic process simulations. The readers will have the opportunity to learn about the basic working principles, design and control of such integrated processes, while also getting a modern overview of the process intensification opportunities for biodiesel synthesis. The target audience consists primarily of students and postgraduates, chemical engineers, researchers, project leaders, technology managers, biodiesel manufacturers, and equipment suppliers.

Acknowledgments

This work is the result of many years of work in the area of reactive separation processes and process intensification technologies for biodiesel production. I am very grateful to everyone who has contributed to make it a possible success, and I especially want to thank my collaborators and co-authors of related scientific articles: Sorin Bildea and Radu Ignat (University ‘Politehnica’ of Bucharest, RO), Alexandre Dimian and Gadi Rothenberg (University of Amsterdam, NL), Florin Omota (Fluor, NL), and Juan Gabriel Segovia-Hernández (Universidad de Guanajuato, MX). Furthermore, I have enjoyed the interesting discussions about process intensification and reactive separations, with some remarkable persons from academia and industry, to whom I am also obliged: Žarco Olujić, Andrzej Stankiewicz and Johan Grievink (*Delft University of Technology, NL*), Sigurd Skogestad (*NTNU Trondheim, NO*), Ivar Halvorsen (*SINTEF ICT, NO*), Jan Harmsen (*Shell Global Solutions, NL*), Andrzej Górak (*Technical University of Dortmund, DE*), as well as a number of other colleagues from the chemical process industry and academia.

In addition, the excellent support and valuable help from the editors Gabriella Anderson and Anthony Doyle (*Springer, UK*) are greatly acknowledged. And last but not least, my special thanks go to my loving wife and supportive family, for their understanding, tremendous care, relentless encouragements, as well as admirable patience with me.

Contents

1	Process Intensification Technologies	1
	References	6
2	Biodiesel and Fatty Esters.	9
	2.1 Biodiesel Production Routes	11
	2.2 Catalysts for Fatty Esters Synthesis	13
	2.3 Industrial Biodiesel Processes	18
	References	20
3	Reactive Separation Processes.	25
	References	29
4	Property Models and Process Simulation.	35
	References	40
5	Reactive Distillation Technology	41
	5.1 RD Experimental Studies	43
	5.2 RD Simulation Studies and Process Design	45
	5.3 Dynamics and Control of Reactive Distillation	48
	5.4 Complex Reactive Distillation Configurations	57
	References	62
6	Reactive Absorption Technology	67
	References	75
7	Reactive Extraction Technology	77
	References	85
8	Membrane Reactors	87
	References	94

9 Centrifugal Contact Separators	97
References	100
10 Concluding Remarks	101
References	102

About the Author

Anton A. Kiss has a Ph.D. in Chemical Engineering and around 15 years of academic research and education experience, supported by a decade of industrial research experience in the area of separation technology, process intensification and process systems engineering. Currently, he works as senior project leader in the Department of Research, Development and Innovation of AkzoNobel—a Global Fortune 500 company, consistently ranked as one of the leaders in sustainability—acting as the key expert in distillation, reactive-separations, and other integrated processes. In his capacity as an award-winning researcher in separation technologies, Dr. Kiss has given many lectures at universities and conferences and has carried out more than 100 research and industrial projects. He has also supervised numerous graduation projects, and has published several textbooks and more than 50 scientific articles in peer-reviewed journals. More details are available on the personal website: <http://www.tonykiss.com>.

Abstract

Process intensification technologies can drastically reduce the overall costs and improve the sustainability of many industrial processes. In particular, reactive separations offer new and exciting opportunities for manufacturing fatty acid alkyl esters involved in the industrial production of biodiesel and specialty chemicals. Biodiesel is a biodegradable and renewable fuel, emerged as a viable alternative to petroleum diesel. In spite of the recent advances, the existing biodiesel processes still suffer from serious problems associated with the use of homogeneous catalysts and the limitations imposed by the chemical reaction equilibrium, thus leading to severe economical and environmental penalties (e.g. high operating costs, salt waste streams).

This work provides a comprehensive overview illustrated with industrially relevant examples of novel reactive separation processes used in the biodiesel production: reactive distillation, reactive absorption, reactive extraction, membrane reactors or centrifugal contact separators. Remarkably, the integration of reaction and separation into one operating unit overcomes the equilibrium limitations and provides major benefits such as low investment and operating costs. Many of these reactive separation processes can be further enhanced by heat integration and also powered by heterogeneous catalysts, to eliminate all conventional catalyst-related operations, increase the efficiency in using the raw materials and the reaction volume, while offering high conversion and selectivity, and significant energy savings. The readers will learn about the working principles, design and control of integrated processes, while getting a state-of-the-art overview of the process intensification opportunities for biodiesel synthesis.

Keywords Reactive distillation · Absorption · Stripping · Extraction · Membranes · Centrifugal contactors