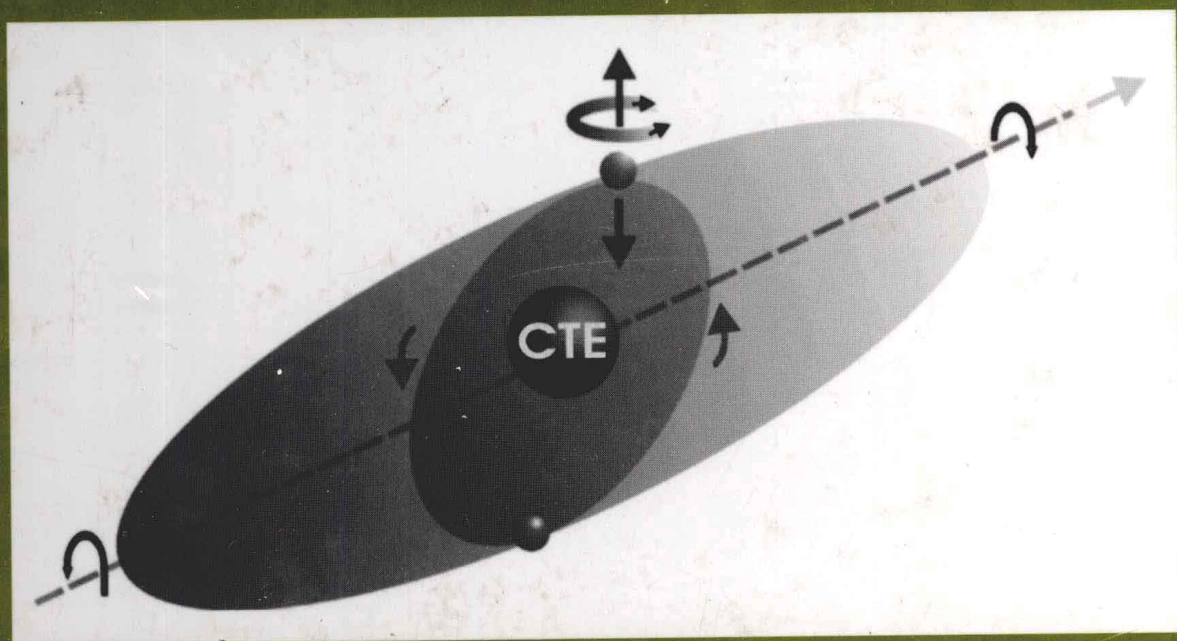


surfactant science series

volume **130**

FINELY DISPERSED PARTICLES

Micro-, Nano-, and Atto-Engineering



edited by
Aleksandar M. Spasic
Jyh-Ping Hsu



Taylor & Francis
Taylor & Francis Group

FINELY DISPERSED PARTICLES

Micro-, Nano-, and Atto-Engineering

Edited by

Aleksandar M. Spasic

***Institute for Technology of Nuclear and Other Mineral Raw Materials
Belgrade, Serbia, Serbia & Montenegro***

Jyh-Ping Hsu

***National Taiwan University
Taipei, Taiwan***



Taylor & Francis

Taylor & Francis Group

Boca Raton London New York

A CRC title, part of the Taylor & Francis imprint, a member of the
Taylor & Francis Group, the academic division of T&F Informa plc.

Published in 2006 by
CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2006 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 1-57444-463-8 (Hardcover)
International Standard Book Number-13: 978-1-57444-463-6 (Hardcover)
Library of Congress Card Number 2005048543

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

No part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Finely dispersed particles : micro-, nano-, and atto-engineering / [edited by] Aleksander M. Spasic & Jyh-Ping Hsu.

p. cm. — (Surfactant science series ; v. 130)

Includes bibliographical references and index.

ISBN 1-57444-463-8

1. Colloids — electric properties 2. Colloids — Transport properties. 3. Colloids — Industrial Applications. 4. Nanoscience. 5. Transport Theory. I. Spasic, Aleksander M. II. Hsu, Jyh-Ping, 1955- III. Series

QD549.F395 2005

620'.5—dc22

2005048543

informa

Taylor & Francis Group
is the Academic Division of Informa plc.

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

FINELY DISPERSED PARTICLES

Micro-, Nano-, and Atto-Engineering

SURFACTANT SCIENCE SERIES

FOUNDING EDITOR

MARTIN J. SCHICK

1918–1998

SERIES EDITOR

ARTHUR T. HUBBARD

*Santa Barbara Science Project
Santa Barbara, California*

ADVISORY BOARD

DANIEL BLANKSCHTEIN

*Department of Chemical Engineering
Massachusetts Institute
of Technology
Cambridge, Massachusetts*

S. KARABORNI

*Shell International Petroleum
Company Limited
London, England*

LISA B. QUENCER

*The Dow Chemical Company
Midland, Michigan*

JOHN F. SCAMEHORN

*Institute for Applied Surfactant Research
University of Oklahoma
Norman, Oklahoma*

P. SOMASUNDARAN

*Henry Krumb School of Mines
Columbia University
New York, New York*

ERIC W. KALER

*Department of Chemical Engineering
University of Delaware
Newark, Delaware*

CLARENCE MILLER

*Department of Chemical Engineering
Rice University
Houston, Texas*

DON RUBINGH

*The Procter & Gamble Company
Cincinnati, Ohio*

BEREND SMIT

*Shell International
Oil Products B.V.
Amsterdam, The Netherlands*

JOHN TEXTER

*Strider Research Corporation
Rochester, New York*

Preface

This book describes recent developments in basic and applied science and engineering of finely dispersed particles and related systems. Written by a team of outstanding scientists, this book takes an interdisciplinary approach to the elucidation of the heat, mass, and momentum transfer phenomena as well as the electron transfer phenomenon, at well-characterized interfaces. The considered scales are milli-, micro-, nano-, and atto-, using both coherence and decoherence theoretical approaches. Milli- and microscales may cover more or less classical chemical engineering insight, while nano- and attoscales focus on modern molecular and atomic engineering. In this context, “atomic engineering” recalls the ancient idea of interplay of particles that are small, indivisible, and integer (Greek “ατομος”). In the recent scientific literature, terms such as nanoscience and nanotechnology, functional artificial nanoarchitectures, nanosystems and molecular machinery, once considered merely futuristic, have become focuses of attention. The aim of this book is to provide the readers with recent concepts in the physics and chemistry of well-studied interfaces of rigid and deformable particles in homo- and hetero-aggregate dispersed systems. As many such systems are non-Newtonian, apart from classical momentum, heat, and mass transfer phenomena, the electron transfer phenomenon is also introduced into their description. Examples of such systems are: emulsions, dispersoids, suspensions, nanopowders, foams, fluosols, polymer membranes, biocolloids, and plasmas. Thus, the central themes of this book are the hydrodynamic, electrodynamic, and thermodynamic instabilities that occur at interfaces and the rheological properties of the interfacial layers responsible for the existence of droplets, particles, and droplet–particle–film structures in finely dispersed systems.

Part I, Introduction, written by Spasic, Mitrovic, and Krstic, gives a brief overview of the finely dispersed systems through their classification considering surface and line continua and point discontinua, states of aggregation, homo and hetero, and their shape, rigid or deformable.

In Part II, General, several overviews are presented, beginning with Ohshima’s chapter on electrokinetic behavior of charged particles and droplets, then Delgado and González-Caballero present a chapter on electrokinetic phenomena in suspensions, followed by Schramm and Stasiuk’s overview of emulsions, and finally Saboni and Alexandrova close this section with heat and mass transfer in finely dispersed systems.

Part II continues with a section on various approaches and transitions. Chapter 6 covers polymer networks and transitions from nano- to macroscale by Plavsic. The following chapter is on the atomic scale imaging of oscillation and chemical waves at catalytic surface reactions by Elokhin and Gorodetskii. Then next chapter relates the characterization of catalysts by means of an oscillatory reaction written by Kolar-Anić, Anić, and Čupić. Then Dugić, Raković, and Plavsic address polymer conformational stability and transitions based on a quantum decoherence theory approach. Chapter 10 of this section, by Jarić and Kuzmanović, presents a perspective of the physics of interfaces from a standpoint of continuum physics.

Finally, Part II ends with a section on tools. The first chapter, written by Petkovska, discusses nonlinear dynamics methods for estimation of equilibrium and kinetics in heterogeneous solid–fluid systems. Then Oldshue discusses current principles of mixing related to the scale up and scale down. This section ends with Jovanić’s chapter on quantification of visual information.

Part III deals with homo-aggregate finely dispersed systems and contains chapters about emulsions, dispersoids, and liquid–liquid dispersions. Oldshue presents a brief chapter on non-Newtonian aspects of emulsification. The following chapter by Spasic, Lazarevic, and Krstic discusses a new theory of electroviscoelasticity using different mathematical tools. Then, a review of

experimental results on the production of mono-dispersed emulsions using Shirasu membranes is presented by Vladislavljevic, Shimizu, Nakashima, Schubert, and Nakajima. The *Dispersoids* section contains a single chapter by Zdujić who gives a short account of the main aspects of the mechanical treatment of inorganic solids. Part III concludes with a chapter by Bart on *Liquid-Liquid Dispersions* introducing reactive extraction in electric fields.

Part IV covers hetero-aggregate finely dispersed systems and includes four chapters. The first section *Foams* contains a chapter written by Creux, Lachaise, and Graciaa on gas bubbles within electric fields. In the chapter on section *Fluosols*, Jokanovic presents nano-designing of structures and substructures in spray pyrolysis processes. Further on, Alexandrova, Amang, Garcia, Rollet, and Saboni address transfer phenomena through polymer membranes. The chapter on *Multiphase Dispersed Systems*, written by Duduković and Nikačević, is concerned with gas-flowing solids-fixed bed contactors. The following chapter discusses reaction and capillary condensation in dispersed porous particles by Ostrovskii and Wood. This section ends with a chapter by Skala and Orlovic on particle production using supercritical fluids.

The book closes with Part V "Hetero-Aggregate Finely Dispersed Systems of Biological Interest" and contains eight chapters under the one section head of *Biocolloids*. Kuo and Hsu begin this section by discussing the effects of electrical field on the behavior of biological cells. Then Dzwinel, Boryczko, and Yuen present methods, algorithms, and results of modeling mesoscopic fluids with discrete particles. That is followed by a chapter discussing nonlinear dynamics of a DNA chain presented by Zdravković. The next chapter, written by Partch, Powell, Lee, Varshney, Shah, Baney, Lee, Dennis, Morey, and Flint, discusses surface modification of dispersed phases designed for *in vivo* removal of overdosed toxins. Following on, Pasqualini and López present their chapter on carbon nanocapsules and their nuclear application. In chapter 30, Markvicheva presents methods of bioencapsulation in polymer micro- and nanocarriers and their application in biomedical fields. The penultimate chapter by Bugarski, Obradovic, Nedovic, and Goosen describes a method of electrostatic droplet generation for cell immobilization. The final chapter of the book, written by Mojovic and Jovanovic, is dedicated to a micro-biosensor based on immobilized cells.

The intended audience of this book includes: chemical engineers — researchers in fundamentals of finely dispersed particles — separation, sorption, membrane processes, nanoscience and nanotechnology; physical chemists — researchers in colloid, biocolloid and interface science; theoretical and applied mechanicians — rheologists; biologists and medicine researchers — hematology, genetics and electroneurophysiology; researchers in food, pharmaceutical, petrochemical, and metallurgical science.

Applications and implications of the material presented in the book are supposed to contribute to the advanced fundamentals of interfacial and colloidal phenomena. Related subject examples are:

- Entrainment problems in solvent extraction
- Colloid and interface science
- Chemical and biochemical sensors
- Electroanalytical methods
- Biology and biomedicine (hematology, genetics, electroneurophysiology)
- Interface surface, line, point and overall barriers-symmetries (surface — bilipid membrane cells, free bubbles of surfactants, Langmuir Blodgett films; line — genes, liquid crystals, microtubules; point — fullerenes, micro-emulsions; overall — dry foams, polymer elastic and rigid foams)

Editors

Aleksandar M. Spasic is a research fellow at Institute for Technology of Nuclear and Other Mineral Raw Materials, Department of Chemical Engineering, Belgrade, Serbia. After he received an IAEA fellowship realized in the Laboratory of Ultra-Refractory Materials, CNRS, Odeillo Font-Romeu, France, his research activities were related to the finely dispersed systems and, in particular, to the electroviscoelastic phenomena at rigid and deformable liquid–liquid interfaces.

Jyh-Ping Hsu is the dean of the College of Engineering, National Ilan University (on leave from the Department of Chemical Engineering, National Taiwan University). Among his research interests are flocculation, adsorption, and electrokinetic phenomena.

Acknowledgment

We would like to thank Professor Arthur T. Hubbard for suggestions and supporting us as the editors of this volume, and also to thank the contributors for their efforts in writing their chapters. Finally, we are pleased to acknowledge the efficiency and care of the people in charge of this project, at Marcel Dekker, Inc., and last but not least, to thank the executive staff of CRC Press and Taylor & Francis.

Aleksandar M. Spasic
*Institute for Technology of Nuclear and
Other Mineral Raw Materials*

Jyh-Ping Hsu
National Taiwan University

Contributors

Silvia Alexandrova

Department of Chemical Engineering
University of Caen
Caen, France

Dieudonné N. Amang

Department of Chemical Engineering
University of Caen
Caen, France

Slobodan Anić

Department of Physical Chemistry
University of Belgrade
Belgrade, Serbia and Montenegro

R. Baney

Department of Materials Science and
Engineering
University of Florida
Gainesville, Florida, USA

Hans-Jörg Bart

Department of Mechanical and
Process Engineering
Institute of Chemical Engineering
Technical University of
Kaiserslautern
Kaiserslautern, Germany

Krzysztof Boryczko

Institute of Computer Science
AGH University of Science and
Technology
Kraków, Poland

Branko M. Bugarski

Department of Chemical Engineering
University of Belgrade,
Belgrade, Serbia and Montenegro

Patrice Creux

Laboratory for Complex Fluids
University of Pau
Pau, France

Željko Čupić

Institute of Chemistry,
Technology and Metallurgy
Belgrade, Serbia and Montenegro

Ángel V. Delgado

Department of Applied Physics
University of Granada
Granada, Spain

D. Dennis

Department of Anesthesiology,
Pharmacology and Experimental
Therapeutics
University of Florida
Gainesville, Florida, USA

Aleksandar P. Duduković

Department of Chemical
Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Miroljub Dugić

Department of Physics
University of Kragujevac
Kragujevac, Serbia and Montenegro

Witold Dzwiniel

Institute of Computer Science
AGH University of Science and
Technology
Kraków, Poland

Vladimir I. Elokhin

Boreskov Institute of Catalysis
Novosibirsk, Russia

J. Flint

Department of Anesthesiology,
Pharmacology and Experimental
Therapeutics
University of Florida
Gainesville, Florida, USA

François Garcia

Department of Chemical Engineering
University of Caen
Caen, France

F. González-Caballero

Department of Applied Physics
University of Granada
Granada, Spain

Mattheus F. A. Goosen

Department of Chemical Engineering
University of Puerto Rico
San Juan, Puerto Rico

Vladimir V. Gorodetskii

Boreskov Institute of Catalysis
Novosibirsk, Russia

Alain Graciaa

Laboratory for Complex Fluids
University of Pau
Pau, France

Jyh-Ping Hsu

Department of Chemical Engineering
National Taiwan University
Taipei, Taiwan

Jovo P. Jarić

Department of Mathematics
University of Belgrade
Belgrade, Serbia and Montenegro

Vukoman Jokanovic

Institute of Technical Sciences
Serbian Academy of Sciences and Arts
Belgrade, Serbia and Montenegro

Predrag B. Jovanić

Department of Chemical
Engineering
Institute for Technology for Nuclear and
Other Mineral Raw Materials
Belgrade, Serbia and Montenegro

Goran N. Jovanovic

Department of Chemical Engineering
Oregon State University
Corvallis, Oregon, USA

Ljiljana Kolar-Anić

Department of Physical Chemistry
University of Belgrade
Belgrade, Serbia and Montenegro

Dimitrije N. Krstic

Department of Metallurgical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Yung-Chih Kuo

Department of Chemical Engineering
National Chung Cheng University
Chia-Yi, Taiwan

Dragoslav S. Kuzmanović

Department of Transport and Traffic
Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Jean Lachaise

Laboratory for Complex Fluids
University of Pau
Pau, France

Mihailo P. Lazarevic

Department of Mechanical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

D-W. Lee

Department of Materials Science and
Engineering
University of Florida
Gainesville, Florida, USA

Y-H. Lee

Department of Chemistry
Kyungwon University
Sungham City, Korea

Marisol López

Department of Nuclear Fuels
National Commission of Atomic Energy
Buenos Aires, Argentina

Elena Markvicheva

Shemyakin and Ovchinnikov Institute of
Bioorganic Chemistry
Moscow, Russia

Milan Mitrovic

Department of Chemical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Ljiljana Mojovic

Department of Biochemical
Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

T. Morey

Department of Anesthesiology,
Pharmacology and Experimental
Therapeutics
University of Florida
Gainesville, Florida, USA

Mitsutoshi Nakajima

National Food Research Institute
Tsukuba, Ibaraki, Japan

Tadao Nakashima

Miyazaki Prefectural Industrial Support
Foundation
Sadowara, Miyazaki, Japan

Viktor A. Nedovic

Department of Food Technology and
Biochemistry
Zemum, University of Belgrade
Belgrade, Serbia and Montenegro

Nikola M. Nikačević

Department of Chemical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Bojana Obradovic

Department of Chemical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Hiroyuki Ohshima

Science University of Tokyo
Tokyo, Japan

James Y. Oldshue

Oldshue Technologies International
Sarasota, Florida, USA

Aleksandar Orlovic

Department of Organic Chemical Technology
University of Belgrade
Belgrade, Serbia and Montenegro

Nickolay M. Ostrovskii

Boreskov Institute of Catalysis
Omsk, Russia

Richard Partch

University of Florida
Gainesville, Florida and
Clarkson University
Potsdam, New York, USA

Enrique E. Pasqualini

Department of Nuclear Fuels
National Commission of Atomic Energy
Buenos Aires, Argentina

Menka Petkovska

Department of Chemical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Milenko Plavsic

Department of Organic Chemical
Technology
University of Belgrade
Belgrade, Serbia and Montenegro

E. Powell

Department of Chemistry
Clarkson University
Potsdam, New York, USA

Dejan Raković

Department of Electrical Engineering
University of Belgrade
Belgrade, Serbia and Montenegro

Véronique Rollet

Department of Chemical Engineering
University of Caen
Caen, France

Abdellah Saboni

Department of Chemical
Processes and Hazards
University of Rouen
Rouen, France

Laurier L. Schramm

Saskatchewan Research Council
Saskatoon and University of Calgary
Calgary, Canada

Helmar Schubert

University of Karlsruhe
Karlsruhe, Germany

D. Shah

Department of Chemical Engineering
University of Florida
Gainesville, Florida, USA

Masataka Shimizu

Miyazaki Prefectural Industrial
Support Foundation
Sadowara, Miyazaki, Japan

Dejan Skala

Department of Organic
Chemical Technology
University of Belgrade
Belgrade, Serbia and Montenegro

Aleksandar M. Spasic

Department of Chemical Engineering
Institute for Technology of Nuclear and
Other Mineral Raw Materials
Belgrade, Serbia and Montenegro

Elaine N. Stasiuk

University of Calgary
Calgary, Canada

M. Varshney

Department of Chemistry
Hamdara University
New Delhi, India

Goran T. Vladisavljevic

Department of Food Technology and
Biochemistry
University of Belgrade
Belgrade-Zemun, Serbia and
Montenegro

Joseph Wood

Center of Formulation Engineering
University of Birmingham
Birmingham, UK

David A. Yuen

Minnesota Supercomputing Institute
University of Minnesota
Minneapolis, Minnesota, USA

Slobodan Zdravković

Department of Electrical Engineering
University of Priština
Kosovska Mitrovica
Serbia and Montenegro

Miodrag Zdujčić

Institute of Technical Sciences
Serbian Academy of Sciences and Arts
Belgrade, Serbia and Montenegro

1. Nonionic Surfactants, *edited by Martin J. Schick* (see also Volumes 19, 23, and 60)
2. Solvent Properties of Surfactant Solutions, *edited by Kozo Shinoda* (see Volume 55)
3. Surfactant Biodegradation, *R. D. Swisher* (see Volume 18)
4. Cationic Surfactants, *edited by Eric Jungermann* (see also Volumes 34, 37, and 53)
5. Detergency: Theory and Test Methods (in three parts), *edited by W. G. Cutler and R. C. Davis* (see also Volume 20)
6. Emulsions and Emulsion Technology (in three parts), *edited by Kenneth J. Lissant*
7. Anionic Surfactants (in two parts), *edited by Warner M. Linfield* (see Volume 56)
8. Anionic Surfactants: Chemical Analysis, *edited by John Cross*
9. Stabilization of Colloidal Dispersions by Polymer Adsorption, *Tatsuo Sato and Richard Ruch*
10. Anionic Surfactants: Biochemistry, Toxicology, Dermatology, *edited by Christian Gloxhuber* (see Volume 43)
11. Anionic Surfactants: Physical Chemistry of Surfactant Action, *edited by E. H. Lucassen-Reynders*
12. Amphoteric Surfactants, *edited by B. R. Bluestein and Clifford L. Hilton* (see Volume 59)
13. Demulsification: Industrial Applications, *Kenneth J. Lissant*
14. Surfactants in Textile Processing, *Arved Datyner*
15. Electrical Phenomena at Interfaces: Fundamentals, Measurements, and Applications, *edited by Ayao Kitahara and Akira Watanabe*
16. Surfactants in Cosmetics, *edited by Martin M. Rieger* (see Volume 68)
17. Interfacial Phenomena: Equilibrium and Dynamic Effects, *Clarence A. Miller and P. Neogi*
18. Surfactant Biodegradation: Second Edition, Revised and Expanded, *R. D. Swisher*
19. Nonionic Surfactants: Chemical Analysis, *edited by John Cross*
20. Detergency: Theory and Technology, *edited by W. Gale Cutler and Erik Kissa*
21. Interfacial Phenomena in Apolar Media, *edited by Hans-Friedrich Eicke and Geoffrey D. Parfitt*
22. Surfactant Solutions: New Methods of Investigation, *edited by Raoul Zana*
23. Nonionic Surfactants: Physical Chemistry, *edited by Martin J. Schick*
24. Microemulsion Systems, *edited by Henri L. Rosano and Marc Clause*
25. Biosurfactants and Biotechnology, *edited by Naim Kosaric, W. L. Cairns, and Neil C. C. Gray*
26. Surfactants in Emerging Technologies, *edited by Milton J. Rosen*
27. Reagents in Mineral Technology, *edited by P. Somasundaran and Brij M. Moudgil*
28. Surfactants in Chemical/Process Engineering, *edited by Darsh T. Wasan, Martin E. Ginn, and Dinesh O. Shah*
29. Thin Liquid Films, *edited by I. B. Ivanov*
30. Microemulsions and Related Systems: Formulation, Solvency, and Physical Properties, *edited by Maurice Bourrel and Robert S. Schechter*
31. Crystallization and Polymorphism of Fats and Fatty Acids, *edited by Nissim Garti and Kiyotaka Sato*
32. Interfacial Phenomena in Coal Technology, *edited by Gregory D. Botsaris and Yuli M. Glazman*
33. Surfactant-Based Separation Processes, *edited by John F. Scamehorn and Jeffrey H. Harwell*
34. Cationic Surfactants: Organic Chemistry, *edited by James M. Richmond*

35. Alkylene Oxides and Their Polymers, *F. E. Bailey, Jr., and Joseph V. Koleske*
36. Interfacial Phenomena in Petroleum Recovery, *edited by Norman R. Morrow*
37. Cationic Surfactants: Physical Chemistry, *edited by Donn N. Rubingh and Paul M. Holland*
38. Kinetics and Catalysis in Microheterogeneous Systems, *edited by M. Grätzel and K. Kalyanasundaram*
39. Interfacial Phenomena in Biological Systems, *edited by Max Bender*
40. Analysis of Surfactants, *Thomas M. Schmitt* (see Volume 96)
41. Light Scattering by Liquid Surfaces and Complementary Techniques, *edited by Dominique Langevin*
42. Polymeric Surfactants, *Irja Piirma*
43. Anionic Surfactants: Biochemistry, Toxicology, Dermatology. Second Edition, Revised and Expanded, *edited by Christian Gloxhuber and Klaus Künstler*
44. Organized Solutions: Surfactants in Science and Technology, *edited by Stig E. Friberg and Björn Lindman*
45. Defoaming: Theory and Industrial Applications, *edited by P. R. Garrett*
46. Mixed Surfactant Systems, *edited by Keizo Ogino and Masahiko Abe*
47. Coagulation and Flocculation: Theory and Applications, *edited by Bohuslav Dobiás*
48. Biosurfactants: Production Properties Applications, *edited by Naim Kosaric*
49. Wettability, *edited by John C. Berg*
50. Fluorinated Surfactants: Synthesis Properties Applications, *Erik Kissa*
51. Surface and Colloid Chemistry in Advanced Ceramics Processing, *edited by Robert J. Pugh and Lennart Bergström*
52. Technological Applications of Dispersions, *edited by Robert B. McKay*
53. Cationic Surfactants: Analytical and Biological Evaluation, *edited by John Cross and Edward J. Singer*
54. Surfactants in Agrochemicals, *Tharwat F. Tadros*
55. Solubilization in Surfactant Aggregates, *edited by Sherill D. Christian and John F. Scamehorn*
56. Anionic Surfactants: Organic Chemistry, *edited by Helmut W. Stache*
57. Foams: Theory, Measurements, and Applications, *edited by Robert K. Prud'homme and Saad A. Khan*
58. The Preparation of Dispersions in Liquids, *H. N. Stein*
59. Amphoteric Surfactants: Second Edition, *edited by Eric G. Lomax*
60. Nonionic Surfactants: Polyoxyalkylene Block Copolymers, *edited by Vaughn M. Nace*
61. Emulsions and Emulsion Stability, *edited by Johan Sjöblom*
62. Vesicles, *edited by Morton Rosoff*
63. Applied Surface Thermodynamics, *edited by A. W. Neumann and Jan K. Spelt*
64. Surfactants in Solution, *edited by Arun K. Chattopadhyay and K. L. Mittal*
65. Detergents in the Environment, *edited by Milan Johann Schwuger*
66. Industrial Applications of Microemulsions, *edited by Conxita Solans and Hironobu Kunieda*
67. Liquid Detergents, *edited by Kuo-Yann Lai*
68. Surfactants in Cosmetics: Second Edition, Revised and Expanded, *edited by Martin M. Rieger and Linda D. Rhein*
69. Enzymes in Detergency, *edited by Jan H. van Ee, Onno Misset, and Erik J. Baas*
70. Structure-Performance Relationships in Surfactants, *edited by Kunio Esumi and Minoru Ueno*

71. Powdered Detergents, *edited by Michael S. Showell*
72. Nonionic Surfactants: Organic Chemistry, *edited by Nico M. van Os*
73. Anionic Surfactants: Analytical Chemistry, Second Edition, Revised and Expanded, *edited by John Cross*
74. Novel Surfactants: Preparation, Applications, and Biodegradability, *edited by Krister Holmberg*
75. Biopolymers at Interfaces, *edited by Martin Malmsten*
76. Electrical Phenomena at Interfaces: Fundamentals, Measurements, and Applications, Second Edition, Revised and Expanded, *edited by Hiroyuki Ohshima and Kunio Furusawa*
77. Polymer-Surfactant Systems, *edited by Jan C. T. Kwak*
78. Surfaces of Nanoparticles and Porous Materials, *edited by James A. Schwarz and Cristian I. Contescu*
79. Surface Chemistry and Electrochemistry of Membranes, *edited by Torben Smith Sørensen*
80. Interfacial Phenomena in Chromatography, *edited by Emile Pefferkorn*
81. Solid-Liquid Dispersions, *Bohuslav Dobiáš, Xueping Qiu, and Wolfgang von Rybinski*
82. Handbook of Detergents, *editor in chief: Uri Zoller Part A: Properties, edited by Guy Broze*
83. Modern Characterization Methods of Surfactant Systems, *edited by Bernard P. Binks*
84. Dispersions: Characterization, Testing, and Measurement, *Erik Kissa*
85. Interfacial Forces and Fields: Theory and Applications, *edited by Jyh-Ping Hsu*
86. Silicone Surfactants, *edited by Randal M. Hill*
87. Surface Characterization Methods: Principles, Techniques, and Applications, *edited by Andrew J. Milling*
88. Interfacial Dynamics, *edited by Nikola Kallay*
89. Computational Methods in Surface and Colloid Science, *edited by Malgorzata Borówko*
90. Adsorption on Silica Surfaces, *edited by Eugène Papirer*
91. Nonionic Surfactants: Alkyl Polyglucosides, *edited by Dieter Balzer and Harald Lüders*
92. Fine Particles: Synthesis, Characterization, and Mechanisms of Growth, *edited by Tadao Sugimoto*
93. Thermal Behavior of Dispersed Systems, *edited by Nissim Garti*
94. Surface Characteristics of Fibers and Textiles, *edited by Christopher M. Pastore and Paul Kiekens*
95. Liquid Interfaces in Chemical, Biological, and Pharmaceutical Applications, *edited by Alexander G. Volkov*
96. Analysis of Surfactants: Second Edition, Revised and Expanded, *Thomas M. Schmitt*
97. Fluorinated Surfactants and Repellents: Second Edition, Revised and Expanded, *Erik Kissa*
98. Detergency of Specialty Surfactants, *edited by Floyd E. Friedli*
99. Physical Chemistry of Polyelectrolytes, *edited by Tsetska Radeva*
100. Reactions and Synthesis in Surfactant Systems, *edited by John Texter*
101. Protein-Based Surfactants: Synthesis, Physicochemical Properties, and Applications, *edited by Ifendu A. Nnanna and Jiding Xia*
102. Chemical Properties of Material Surfaces, *Marek Kosmulski*

103. Oxide Surfaces, *edited by James A. Wingrave*
104. Polymers in Particulate Systems: Properties and Applications, *edited by Vincent A. Hackley, P. Somasundaran, and Jennifer A. Lewis*
105. Colloid and Surface Properties of Clays and Related Minerals, *Rossman F. Giese and Carel J. van Oss*
106. Interfacial Electrokinetics and Electrophoresis, *edited by Ángel V. Delgado*
107. Adsorption: Theory, Modeling, and Analysis, *edited by József Tóth*
108. Interfacial Applications in Environmental Engineering, *edited by Mark A. Keane*
109. Adsorption and Aggregation of Surfactants in Solution, *edited by K. L. Mittal and Dinesh O. Shah*
110. Biopolymers at Interfaces: Second Edition, Revised and Expanded, *edited by Martin Malmsten*
111. Biomolecular Films: Design, Function, and Applications, *edited by James F. Rusling*
112. Structure–Performance Relationships in Surfactants: Second Edition, Revised and Expanded, *edited by Kunio Esumi and Minoru Ueno*
113. Liquid Interfacial Systems: Oscillations and Instability, *Rudolph V. Birikh, Vladimir A. Briskman, Manuel G. Velarde, and Jean-Claude Legros*
114. Novel Surfactants: Preparation, Applications, and Biodegradability: Second Edition, Revised and Expanded, *edited by Krister Holmberg*
115. Colloidal Polymers: Synthesis and Characterization, *edited by Abdelhamid Elaissari*
116. Colloidal Biomolecules, Biomaterials, and Biomedical Applications, *edited by Abdelhamid Elaissari*
117. Gemini Surfactants: Synthesis, Interfacial and Solution-Phase Behavior, and Applications, *edited by Raoul Zana and Jiding Xia*
118. Colloidal Science of Flotation, *Anh V. Nguyen and Hans Joachim Schulze*
119. Surface and Interfacial Tension: Measurement, Theory, and Applications, *edited by Stanley Hartland*
120. Microporous Media: Synthesis, Properties, and Modeling, *Freddy Romm*
121. Handbook of Detergents, *editor in chief: Uri Zoller* Part B: Environmental Impact, *edited by Uri Zoller*
122. Luminous Chemical Vapor Deposition and Interface Engineering, *Hirotsugu Yasuda*
123. Handbook of Detergents, *editor in chief: Uri Zoller* Part C: Analysis, *edited by Heinrich Waldhoff and Rüdiger Spilker*
124. Mixed Surfactant Systems: Second Edition, Revised and Expanded, *edited by Masahiko Abe and John F. Scamehorn*
125. Dynamics of Surfactant Self-Assemblies: Micelles, Microemulsions, Vesicles and Lyotropic Phases, *edited by Raoul Zana*
126. Coagulation and Flocculation: Second Edition, *edited by Hansjoachim Stechemesser and Bohulav Dobiás*
127. Bicontinuous Liquid Crystals, *edited by Matthew L. Lynch and Patrick T. Spicer*
128. Handbook of Detergents, *editor in chief: Uri Zoller* Part D: Formulation, *edited by Michael S. Showell*
129. Liquid Detergents: Second Edition, *edited by Kuo-Yann Lai*
130. Finely Dispersed Particles: Micro-, Nano-, and Atto-Engineering, *edited by Aleksandar M. Spasic and Jyh-Ping Hsu*