CONTENTS

CHEMICAL ENGINEERING AND CHEMICAL PROCESS TECHNOLOGY



Chemical Engineering and Chemical Process Technology Volume 1 e-ISBN: 978-1-84826-396-3 ISBN : 978-1-84826-846-3 No. of Pages: 476

Chemical Engineering and Chemical Process Technology Volume 2 e-ISBN: 978-1-84826-397-0 ISBN : 978-1-84826-847-0 No. of Pages: 404

Chemical Engineering and Chemical Process Technology Volume 3 e-ISBN: 978-1-84826-398-7 ISBN : 978-1-84826-848-7 No. of Pages: 338

Chemical Engineering and Chemical Process Technology Volume 4

e-ISBN: 978-1-84826-399-4 ISBN : 978-1-84826-849-4 No. of Pages: 424

Chemical Engineering and Chemical Process Technology Volume 5

e-ISBN: 978-1-84826-400-7 ISBN : 978-1-84826-850-0 No. of Pages: 338

Chemical Engineering and Chemical Process Technology Volume 6

e-ISBN: 978-1-84826-414-4 ISBN : 978-1-84826-864-7 No. of Pages: 526

Chemical Engineering and Chemical Process Technology Volume 7 e-ISBN: 978-1-84826-415-1 ISBN : 978-1-84826-865-4 No. of Pages: 496

For more information of e-book and Print Volume(s) order, <u>please click here</u> Or contact : eolssunesco@gmail.com

CONTENTS

Preface

xxxvii

1

VOLUME I

Principles Of Momentum, Mass And Energy Balances

Leon Gradoń, Faculty of Chemical and Process Engineering, Warsaw University of Technology, Warsaw, Poland

- 1. Introduction
- 2. Macroscopic balances
 - 2.1. Process Classification and Types of Balances
 - 2.2. Mass Balances
 - 2.3. Energy Balances
- 3. Microscopic balances
 - 3.1. Continuum and Field Quantities
 - 3.2. Conservation Equation for Continuum
 - 3.3. Balance of Linear Momentum
 - 3.4. Mass Balance
 - 3.5. Energy Balance
- 4. Population balances
 - 4.1. Age Distribution Functions
 - 4.2. General Population Balance

Thermodynamics of Chemical Processes

22

G.Maurer, Department of Mechanical and Process Engineering, University of Kaiserslautern, Germany

- 1. Introduction
- 2. Fundamental Laws of Thermodynamics
 - 2.1. Temperature: Definition and Scale
 - 2.2. The First Law of Thermodynamics
 - 2.3. The Second Law of Thermodynamics
 - 2.4. Absolute Numbers for the Internal Energy and the Enthalpy
 - 2.5. The Third Law of Thermodynamics Absolute Entropy
- 3. Properties of Pure Fluids
 - 3.1. Volumetric Properties
 - 3.2. Caloric Properties
 - 3.3. Entropy Differences and Fundamental Equations
- 4. Phase Equilibrium Thermodynamics
 - 4.1. Basic Relations
 - 4.2. Examples for Phase Equilibrium in Binary Systems
 - 4.2.1. Vapor-liquid Equilibrium
 - 4.2.1.1. Simple systems
 - 4.2.1.2. Azeotropic behavior
 - 4.2.1.3. Gas solubility
 - 4.2.1.4. High-pressure phase equilibrium
 - 4.2.2. Liquid-liquid Equilibrium
 - 4.2.3. Solid-liquid Equilibrium
 - 4.3. Calculation of Phase Equilibrium Properties
 - 4.3.1. Vapor-liquid Equilibrium
 - 4.3.1.1. Fugacity and activity
 - 4.3.1.2. Raoult's law and its generalization
 - 4.3.1.3. Henry's law and its generalization
 - 4.3.1.4. High-pressure phase equilibrium

- 4.3.2. Liquid-liquid Equilibrium
- 4.3.3. Solid-liquid Equilibrium
- 5. Chemical Reacting Mixtures and Chemical Reaction Equilibrium
- 6. Calculation of Fugacities and Activities
 - 6.1. Equations of State
 - 6.2. Equations for the Excess Gibbs Energy
- 7. Conclusions

Fluid Mechanics

Silvana Cardoso, University of Cambridge, UK

- 1. Introduction
- 2. The Continuum Hypothesis
- 3. Conservation Equations
 - 3.1. Conservation of Mass: The Continuity Equation
 - 3.2. Conservation of Momentum: The Navier-Stokes Equations
- 3.3. Initial and Boundary Conditions
- 4. Non-dimensionalization of the Governing Equations: The Reynolds number
- 5. Laminar and Turbulent Flows
- 6. Application of the Equations of Motion: Flow in a Circular Pipe
- 7. Motion of an Isolated Solid Particle in a Fluid
- 8. Particles Settling in a Suspension

Multiphase Flow

B.J. Azzopardi, Department of Chemical and Environmental Engineering, University of Nottingham, Nottingham, UK

1. Introduction

- 2. Gas/Liquid Flows
 - 2.1. Flow Patterns
 - 2.1.1. Definition and Importance of Flow Patterns
 - 2.1.2. Vertical Flow in Pipes
 - 2.1.3. Horizontal Flow in Pipes
 - 2.1.4. Pipes at Other Inclinations
 - 2.2. Flow Pattern Maps
 - 2.2.1. Vertical Flow in Pipes
 - 2.2.2. Horizontal Flow in Pipes
 - 2.3. Empirical Methods for Pressure Drop in Pipes
 - 2.3.1 Separated Flow Concept
 - 2.3.2 Momentum Equation
 - 2.3.3. Void Fraction Equations
 - 2.3.4. Frictional Pressure Drop Equations
 - 2.4. Pressure Drop across Pipe Fittings and Shell Side Flows
 - 2.5. Models for Flow Pattern Transitions
 - 2.6. Flow Pattern Specific Models for Pressure Drop
 - 2.7 Bubble Columns
 - 2.8. Foams
- 3. Liquid/Liquid Flows
- 4. Gas/Solids Flows
- 5. Liquid/Solids Flows
- 6. Modern modeling methods

Heat Transfer

H. Martin, Thermische Verfahrenstechnik, Karlsruhe Institute of Technology (KIT), Germany

130

1. Concepts, basic laws, typical orders of magnitude

- 1.1. Heat, Work, and the First Law of Thermodynamics
- 1.2. Kinetics of Heat Transfer
- 1.3. Orders of Magnitude of Heat Rates and Heat Fluxes
- 1.4. Orders of Magnitude of Relevant Physical Properties
 - 1.4.1. Emissivities
 - 1.4.2. Volumetric Heat Capacities
- 1.4.3. Thermal Conductivity 2. Prediction of heat transfer coefficients
 - 2.1. Heat Transfer Coefficients for Radiation and Conduction and Their Orders of Magnitude
 - 2.2. Steady State Heat Conduction in Stagnant Media
 - 2.3. Transient Heat Conduction in Stagnant Media
 - 2.4. Heat Transfer in Steady Flow Through Channels
 - 2.5. Heat Transfer to Submerged Solids in Cross Flow
 - 2.5.1. The Flat Plate
 - 2.5.2. The single cylinder
 - 2.5.3. The Single Sphere
 - 2.6. Heat Transfer to Tube Bundles and Packed Beds.
 - 2.6.1. Tube Bundles
 - 2.6.2. Packed Beds
 - 2.7. Heat Transfer in Density-gradient-driven Flows
 - 2.7.1. Thermal Transpiration, and Thermal Creeping Flow
 - 2.7.2. Heat Transfer in Buoyancy-driven Flows
 - 2.8. Condensation and Evaporation
- 2.8.1. Condensation
- 2.8.2. Evaporation
- 3. Conclusions

Mass Transfer by Diffusion

A. Burghardt, Institute of Chemical Engineering, Polish Academy of Sciences, Poland

175

- 1. Introduction
- 2. Velocities and Fluxes of Mass Transfer
- 3. Binary Diffusion
 - 3.1. Fick's Law of Diffusion
 - 3.2. Diffusion Coefficients in Gases
 - 3.3. Diffusion Coefficients in Liquids
 - 3.4. Diffusion in Polymers
- 4. Generalized Mass Balances
 - 4.1. Continuity Equations for Binary Systems
- 5. Binary Mass Transfer in Stagnant Systems and in Laminar Flow
 - 5.1. Equimolar Counterdiffusion
 - 5.2. Diffusion Through Stagnant Gas Film
 - 5.3. Gas Absorption into a Falling Liquid Film
 - 5.4. Mass Transfer and Chemical Reaction inside a Porous Catalyst Pellet
- 6. Multicomponent Diffusion
 - 6.1. The Generalized Fick's Law
 - 6.2. The Maxwell Stefan Relations 6.2.1. Multicomponent Equimolar Diffusion

Interphase Mass Transfer

A. Burghardt, Institute of Chemical Engineering, Polish Academy of Sciences, Poland

- 1. Introduction
- 2. Turbulent Mass Transfer
- 3. Mass Transfer Coefficient in One Phase
- 4. Mass Transfer Models

CONTENTS

Preface

xxxvii

1

VOLUME I

Principles Of Momentum, Mass And Energy Balances

Leon Gradoń, Faculty of Chemical and Process Engineering, Warsaw University of Technology, Warsaw, Poland

- 1. Introduction
- 2. Macroscopic balances
 - 2.1. Process Classification and Types of Balances
 - 2.2. Mass Balances
 - 2.3. Energy Balances
- 3. Microscopic balances
 - 3.1. Continuum and Field Quantities
 - 3.2. Conservation Equation for Continuum
 - 3.3. Balance of Linear Momentum
 - 3.4. Mass Balance
 - 3.5. Energy Balance
- 4. Population balances
 - 4.1. Age Distribution Functions
 - 4.2. General Population Balance

Thermodynamics of Chemical Processes

22

G.Maurer, Department of Mechanical and Process Engineering, University of Kaiserslautern, Germany

- 1. Introduction
- 2. Fundamental Laws of Thermodynamics
 - 2.1. Temperature: Definition and Scale
 - 2.2. The First Law of Thermodynamics
 - 2.3. The Second Law of Thermodynamics
 - 2.4. Absolute Numbers for the Internal Energy and the Enthalpy
 - 2.5. The Third Law of Thermodynamics Absolute Entropy
- 3. Properties of Pure Fluids
 - 3.1. Volumetric Properties
 - 3.2. Caloric Properties
 - 3.3. Entropy Differences and Fundamental Equations
- 4. Phase Equilibrium Thermodynamics
 - 4.1. Basic Relations
 - 4.2. Examples for Phase Equilibrium in Binary Systems
 - 4.2.1. Vapor-liquid Equilibrium
 - 4.2.1.1. Simple systems
 - 4.2.1.2. Azeotropic behavior
 - 4.2.1.3. Gas solubility
 - 4.2.1.4. High-pressure phase equilibrium
 - 4.2.2. Liquid-liquid Equilibrium
 - 4.2.3. Solid-liquid Equilibrium
 - 4.3. Calculation of Phase Equilibrium Properties
 - 4.3.1. Vapor-liquid Equilibrium
 - 4.3.1.1. Fugacity and activity
 - 4.3.1.2. Raoult's law and its generalization
 - 4.3.1.3. Henry's law and its generalization
 - 4.3.1.4. High-pressure phase equilibrium

- 4.3.2. Liquid-liquid Equilibrium
- 4.3.3. Solid-liquid Equilibrium
- 5. Chemical Reacting Mixtures and Chemical Reaction Equilibrium
- 6. Calculation of Fugacities and Activities
 - 6.1. Equations of State
 - 6.2. Equations for the Excess Gibbs Energy
- 7. Conclusions

Fluid Mechanics

Silvana Cardoso, University of Cambridge, UK

- 1. Introduction
- 2. The Continuum Hypothesis
- 3. Conservation Equations
 - 3.1. Conservation of Mass: The Continuity Equation
 - 3.2. Conservation of Momentum: The Navier-Stokes Equations
- 3.3. Initial and Boundary Conditions
- 4. Non-dimensionalization of the Governing Equations: The Reynolds number
- 5. Laminar and Turbulent Flows
- 6. Application of the Equations of Motion: Flow in a Circular Pipe
- 7. Motion of an Isolated Solid Particle in a Fluid
- 8. Particles Settling in a Suspension

Multiphase Flow

B.J. Azzopardi, Department of Chemical and Environmental Engineering, University of Nottingham, Nottingham, UK

1. Introduction

- 2. Gas/Liquid Flows
 - 2.1. Flow Patterns
 - 2.1.1. Definition and Importance of Flow Patterns
 - 2.1.2. Vertical Flow in Pipes
 - 2.1.3. Horizontal Flow in Pipes
 - 2.1.4. Pipes at Other Inclinations
 - 2.2. Flow Pattern Maps
 - 2.2.1. Vertical Flow in Pipes
 - 2.2.2. Horizontal Flow in Pipes
 - 2.3. Empirical Methods for Pressure Drop in Pipes
 - 2.3.1 Separated Flow Concept
 - 2.3.2 Momentum Equation
 - 2.3.3. Void Fraction Equations
 - 2.3.4. Frictional Pressure Drop Equations
 - 2.4. Pressure Drop across Pipe Fittings and Shell Side Flows
 - 2.5. Models for Flow Pattern Transitions
 - 2.6. Flow Pattern Specific Models for Pressure Drop
 - 2.7 Bubble Columns
 - 2.8. Foams
- 3. Liquid/Liquid Flows
- 4. Gas/Solids Flows
- 5. Liquid/Solids Flows
- 6. Modern modeling methods

Heat Transfer

H. Martin, Thermische Verfahrenstechnik, Karlsruhe Institute of Technology (KIT), Germany

130

1. Concepts, basic laws, typical orders of magnitude

©Encyclopedia of Life Support Systems (EOLSS)

- 4.1. The Film Theory
- 4.2. The Penetration Theory
- 4.3. The Surface Renewal Theory
- 4.4. The Boundary Layer Theory
 - 4.4.1. Introduction
 - 4.4.2. The Boundary Layer for Momentum Transfer
 - 4.4.3. The Boundary Layer for Mass Transfer
- 4.5. Mass Transfer Coefficients at High Net Mass Transfer Rates
- 4.6. Mass Transfer across a Phase Boundary
- 5. Correlations of Mass Transfer Coefficients
- 6. Multicomponent Mass Transfer

Chemical And Biochemical Kinetics And Macrokinetics

Jim Pfaendtner, Department of Chemistry and applied Biosciences, ETH Zürich" to "Department of Chemical Engineering, The University of Washington, USA

- 1. Introduction
 - 1.1. Classification of Chemical Reactions
 - 1.2. Definition of the Reaction Rate
 - 1.2.1. Factors Affecting the Reaction Rate
- 2. Analysis of common reactions
 - 2.1 Zero, First and Second Order Reactions
 - 2.2 Reversible Reactions and Equilibrium
- 3. Analysis of heterogeneous systems
 - 3.1 Model Heterogeneous Reaction Mechanism
 - 3.3 Regimes of Kinetic and Diffusion Control
 - 3.4 Biochemical Reactions in Heterogeneous Environments
- 4. Analysis of experimental data
- 5. Theories for predicting the reaction rate
 - 5.1 The Arrhenius Model
 - 5.2 Collision Theory
 - 5.3. The RRK Model
 - 5.4. Transition State Theory

Catalysis And Biocatalysis

Dmitry Yu. Murzin, Department of Chemical Engineering, Åbo Akademi University, Åbo/Turku, Finland

- 1. Brief history
- 2. Catalysis-Overview
- 3. Catalytic Kinetics
- 4. Heterogeneous Catalysis
 - 4.1. Classification
 - 4.2. Elementary Steps
- 5. Homogeneous Catalysis
 - 5.1. Gas-phase Catalysis
 - 5.2. Acid-base catalysis
- 5.3. Catalysis by Transition Metals
- 6. Biocatalysis (Catalysis by Enzymes)
- 7. Catalysis and Green Chemistry
- 8. Conclusions

Molecular Simulations

Vlasis G. Mavrantzas, University of Patras, Department of Chemical Engineering and FORTH-ICE/HT, Greece

1. Introduction

iv

344

303

CONTENTS

Preface

xxxvii

1

VOLUME I

Principles Of Momentum, Mass And Energy Balances

Leon Gradoń, Faculty of Chemical and Process Engineering, Warsaw University of Technology, Warsaw, Poland

- 1. Introduction
- 2. Macroscopic balances
 - 2.1. Process Classification and Types of Balances
 - 2.2. Mass Balances
 - 2.3. Energy Balances
- 3. Microscopic balances
 - 3.1. Continuum and Field Quantities
 - 3.2. Conservation Equation for Continuum
 - 3.3. Balance of Linear Momentum
 - 3.4. Mass Balance
 - 3.5. Energy Balance
- 4. Population balances
 - 4.1. Age Distribution Functions
 - 4.2. General Population Balance

Thermodynamics of Chemical Processes

22

G.Maurer, Department of Mechanical and Process Engineering, University of Kaiserslautern, Germany

- 1. Introduction
- 2. Fundamental Laws of Thermodynamics
 - 2.1. Temperature: Definition and Scale
 - 2.2. The First Law of Thermodynamics
 - 2.3. The Second Law of Thermodynamics
 - 2.4. Absolute Numbers for the Internal Energy and the Enthalpy
 - 2.5. The Third Law of Thermodynamics Absolute Entropy
- 3. Properties of Pure Fluids
 - 3.1. Volumetric Properties
 - 3.2. Caloric Properties
 - 3.3. Entropy Differences and Fundamental Equations
- 4. Phase Equilibrium Thermodynamics
 - 4.1. Basic Relations
 - 4.2. Examples for Phase Equilibrium in Binary Systems
 - 4.2.1. Vapor-liquid Equilibrium
 - 4.2.1.1. Simple systems
 - 4.2.1.2. Azeotropic behavior
 - 4.2.1.3. Gas solubility
 - 4.2.1.4. High-pressure phase equilibrium
 - 4.2.2. Liquid-liquid Equilibrium
 - 4.2.3. Solid-liquid Equilibrium
 - 4.3. Calculation of Phase Equilibrium Properties
 - 4.3.1. Vapor-liquid Equilibrium
 - 4.3.1.1. Fugacity and activity
 - 4.3.1.2. Raoult's law and its generalization
 - 4.3.1.3. Henry's law and its generalization
 - 4.3.1.4. High-pressure phase equilibrium

- 4.3.2. Liquid-liquid Equilibrium
- 4.3.3. Solid-liquid Equilibrium
- 5. Chemical Reacting Mixtures and Chemical Reaction Equilibrium
- 6. Calculation of Fugacities and Activities
 - 6.1. Equations of State
 - 6.2. Equations for the Excess Gibbs Energy
- 7. Conclusions

Fluid Mechanics

Silvana Cardoso, University of Cambridge, UK

- 1. Introduction
- 2. The Continuum Hypothesis
- 3. Conservation Equations
 - 3.1. Conservation of Mass: The Continuity Equation
 - 3.2. Conservation of Momentum: The Navier-Stokes Equations
- 3.3. Initial and Boundary Conditions
- 4. Non-dimensionalization of the Governing Equations: The Reynolds number
- 5. Laminar and Turbulent Flows
- 6. Application of the Equations of Motion: Flow in a Circular Pipe
- 7. Motion of an Isolated Solid Particle in a Fluid
- 8. Particles Settling in a Suspension

Multiphase Flow

B.J. Azzopardi, Department of Chemical and Environmental Engineering, University of Nottingham, Nottingham, UK

1. Introduction

- 2. Gas/Liquid Flows
 - 2.1. Flow Patterns
 - 2.1.1. Definition and Importance of Flow Patterns
 - 2.1.2. Vertical Flow in Pipes
 - 2.1.3. Horizontal Flow in Pipes
 - 2.1.4. Pipes at Other Inclinations
 - 2.2. Flow Pattern Maps
 - 2.2.1. Vertical Flow in Pipes
 - 2.2.2. Horizontal Flow in Pipes
 - 2.3. Empirical Methods for Pressure Drop in Pipes
 - 2.3.1 Separated Flow Concept
 - 2.3.2 Momentum Equation
 - 2.3.3. Void Fraction Equations
 - 2.3.4. Frictional Pressure Drop Equations
 - 2.4. Pressure Drop across Pipe Fittings and Shell Side Flows
 - 2.5. Models for Flow Pattern Transitions
 - 2.6. Flow Pattern Specific Models for Pressure Drop
 - 2.7 Bubble Columns
 - 2.8. Foams
- 3. Liquid/Liquid Flows
- 4. Gas/Solids Flows
- 5. Liquid/Solids Flows
- 6. Modern modeling methods

Heat Transfer

H. Martin, Thermische Verfahrenstechnik, Karlsruhe Institute of Technology (KIT), Germany

130

1. Concepts, basic laws, typical orders of magnitude

- 1.1. Heat, Work, and the First Law of Thermodynamics
- 1.2. Kinetics of Heat Transfer
- 1.3. Orders of Magnitude of Heat Rates and Heat Fluxes
- 1.4. Orders of Magnitude of Relevant Physical Properties
 - 1.4.1. Emissivities
 - 1.4.2. Volumetric Heat Capacities
- 1.4.3. Thermal Conductivity 2. Prediction of heat transfer coefficients
 - 2.1. Heat Transfer Coefficients for Radiation and Conduction and Their Orders of Magnitude
 - 2.2. Steady State Heat Conduction in Stagnant Media
 - 2.3. Transient Heat Conduction in Stagnant Media
 - 2.4. Heat Transfer in Steady Flow Through Channels
 - 2.5. Heat Transfer to Submerged Solids in Cross Flow
 - 2.5.1. The Flat Plate
 - 2.5.2. The single cylinder
 - 2.5.3. The Single Sphere
 - 2.6. Heat Transfer to Tube Bundles and Packed Beds.
 - 2.6.1. Tube Bundles
 - 2.6.2. Packed Beds
 - 2.7. Heat Transfer in Density-gradient-driven Flows
 - 2.7.1. Thermal Transpiration, and Thermal Creeping Flow
 - 2.7.2. Heat Transfer in Buoyancy-driven Flows
 - 2.8. Condensation and Evaporation
- 2.8.1. Condensation
- 2.8.2. Evaporation
- 3. Conclusions

Mass Transfer by Diffusion

A. Burghardt, Institute of Chemical Engineering, Polish Academy of Sciences, Poland

175

- 1. Introduction
- 2. Velocities and Fluxes of Mass Transfer
- 3. Binary Diffusion
 - 3.1. Fick's Law of Diffusion
 - 3.2. Diffusion Coefficients in Gases
 - 3.3. Diffusion Coefficients in Liquids
 - 3.4. Diffusion in Polymers
- 4. Generalized Mass Balances
 - 4.1. Continuity Equations for Binary Systems
- 5. Binary Mass Transfer in Stagnant Systems and in Laminar Flow
 - 5.1. Equimolar Counterdiffusion
 - 5.2. Diffusion Through Stagnant Gas Film
 - 5.3. Gas Absorption into a Falling Liquid Film
 - 5.4. Mass Transfer and Chemical Reaction inside a Porous Catalyst Pellet
- 6. Multicomponent Diffusion
 - 6.1. The Generalized Fick's Law
 - 6.2. The Maxwell Stefan Relations 6.2.1. Multicomponent Equimolar Diffusion

Interphase Mass Transfer

A. Burghardt, Institute of Chemical Engineering, Polish Academy of Sciences, Poland

- 1. Introduction
- 2. Turbulent Mass Transfer
- 3. Mass Transfer Coefficient in One Phase
- 4. Mass Transfer Models

CONTENTS

Preface

xxxvii

1

VOLUME I

Principles Of Momentum, Mass And Energy Balances

Leon Gradoń, Faculty of Chemical and Process Engineering, Warsaw University of Technology, Warsaw, Poland

- 1. Introduction
- 2. Macroscopic balances
 - 2.1. Process Classification and Types of Balances
 - 2.2. Mass Balances
 - 2.3. Energy Balances
- 3. Microscopic balances
 - 3.1. Continuum and Field Quantities
 - 3.2. Conservation Equation for Continuum
 - 3.3. Balance of Linear Momentum
 - 3.4. Mass Balance
 - 3.5. Energy Balance
- 4. Population balances
 - 4.1. Age Distribution Functions
 - 4.2. General Population Balance

Thermodynamics of Chemical Processes

22

G.Maurer, Department of Mechanical and Process Engineering, University of Kaiserslautern, Germany

- 1. Introduction
- 2. Fundamental Laws of Thermodynamics
 - 2.1. Temperature: Definition and Scale
 - 2.2. The First Law of Thermodynamics
 - 2.3. The Second Law of Thermodynamics
 - 2.4. Absolute Numbers for the Internal Energy and the Enthalpy
 - 2.5. The Third Law of Thermodynamics Absolute Entropy
- 3. Properties of Pure Fluids
 - 3.1. Volumetric Properties
 - 3.2. Caloric Properties
 - 3.3. Entropy Differences and Fundamental Equations
- 4. Phase Equilibrium Thermodynamics
 - 4.1. Basic Relations
 - 4.2. Examples for Phase Equilibrium in Binary Systems
 - 4.2.1. Vapor-liquid Equilibrium
 - 4.2.1.1. Simple systems
 - 4.2.1.2. Azeotropic behavior
 - 4.2.1.3. Gas solubility
 - 4.2.1.4. High-pressure phase equilibrium
 - 4.2.2. Liquid-liquid Equilibrium
 - 4.2.3. Solid-liquid Equilibrium
 - 4.3. Calculation of Phase Equilibrium Properties
 - 4.3.1. Vapor-liquid Equilibrium
 - 4.3.1.1. Fugacity and activity
 - 4.3.1.2. Raoult's law and its generalization
 - 4.3.1.3. Henry's law and its generalization
 - 4.3.1.4. High-pressure phase equilibrium

- 4.3.2. Liquid-liquid Equilibrium
- 4.3.3. Solid-liquid Equilibrium
- 5. Chemical Reacting Mixtures and Chemical Reaction Equilibrium
- 6. Calculation of Fugacities and Activities
 - 6.1. Equations of State
 - 6.2. Equations for the Excess Gibbs Energy
- 7. Conclusions

Fluid Mechanics

Silvana Cardoso, University of Cambridge, UK

- 1. Introduction
- 2. The Continuum Hypothesis
- 3. Conservation Equations
 - 3.1. Conservation of Mass: The Continuity Equation
 - 3.2. Conservation of Momentum: The Navier-Stokes Equations
- 3.3. Initial and Boundary Conditions
- 4. Non-dimensionalization of the Governing Equations: The Reynolds number
- 5. Laminar and Turbulent Flows
- 6. Application of the Equations of Motion: Flow in a Circular Pipe
- 7. Motion of an Isolated Solid Particle in a Fluid
- 8. Particles Settling in a Suspension

Multiphase Flow

B.J. Azzopardi, Department of Chemical and Environmental Engineering, University of Nottingham, Nottingham, UK

1. Introduction

- 2. Gas/Liquid Flows
 - 2.1. Flow Patterns
 - 2.1.1. Definition and Importance of Flow Patterns
 - 2.1.2. Vertical Flow in Pipes
 - 2.1.3. Horizontal Flow in Pipes
 - 2.1.4. Pipes at Other Inclinations
 - 2.2. Flow Pattern Maps
 - 2.2.1. Vertical Flow in Pipes
 - 2.2.2. Horizontal Flow in Pipes
 - 2.3. Empirical Methods for Pressure Drop in Pipes
 - 2.3.1 Separated Flow Concept
 - 2.3.2 Momentum Equation
 - 2.3.3. Void Fraction Equations
 - 2.3.4. Frictional Pressure Drop Equations
 - 2.4. Pressure Drop across Pipe Fittings and Shell Side Flows
 - 2.5. Models for Flow Pattern Transitions
 - 2.6. Flow Pattern Specific Models for Pressure Drop
 - 2.7 Bubble Columns
 - 2.8. Foams
- 3. Liquid/Liquid Flows
- 4. Gas/Solids Flows
- 5. Liquid/Solids Flows
- 6. Modern modeling methods

Heat Transfer

H. Martin, Thermische Verfahrenstechnik, Karlsruhe Institute of Technology (KIT), Germany

130

1. Concepts, basic laws, typical orders of magnitude

©Encyclopedia of Life Support Systems (EOLSS)

- 4.1. The Film Theory
- 4.2. The Penetration Theory
- 4.3. The Surface Renewal Theory
- 4.4. The Boundary Layer Theory
 - 4.4.1. Introduction
 - 4.4.2. The Boundary Layer for Momentum Transfer
 - 4.4.3. The Boundary Layer for Mass Transfer
- 4.5. Mass Transfer Coefficients at High Net Mass Transfer Rates
- 4.6. Mass Transfer across a Phase Boundary
- 5. Correlations of Mass Transfer Coefficients
- 6. Multicomponent Mass Transfer

Chemical And Biochemical Kinetics And Macrokinetics

Jim Pfaendtner, Department of Chemistry and applied Biosciences, ETH Zürich" to "Department of Chemical Engineering, The University of Washington, USA

- 1. Introduction
 - 1.1. Classification of Chemical Reactions
 - 1.2. Definition of the Reaction Rate
 - 1.2.1. Factors Affecting the Reaction Rate
- 2. Analysis of common reactions
 - 2.1 Zero, First and Second Order Reactions
 - 2.2 Reversible Reactions and Equilibrium
- 3. Analysis of heterogeneous systems
 - 3.1 Model Heterogeneous Reaction Mechanism
 - 3.3 Regimes of Kinetic and Diffusion Control
 - 3.4 Biochemical Reactions in Heterogeneous Environments
- 4. Analysis of experimental data
- 5. Theories for predicting the reaction rate
 - 5.1 The Arrhenius Model
 - 5.2 Collision Theory
 - 5.3. The RRK Model
 - 5.4. Transition State Theory

Catalysis And Biocatalysis

Dmitry Yu. Murzin, Department of Chemical Engineering, Åbo Akademi University, Åbo/Turku, Finland

- 1. Brief history
- 2. Catalysis-Overview
- 3. Catalytic Kinetics
- 4. Heterogeneous Catalysis
 - 4.1. Classification
 - 4.2. Elementary Steps
- 5. Homogeneous Catalysis
 - 5.1. Gas-phase Catalysis
 - 5.2. Acid-base catalysis
- 5.3. Catalysis by Transition Metals
- 6. Biocatalysis (Catalysis by Enzymes)
- 7. Catalysis and Green Chemistry
- 8. Conclusions

Molecular Simulations

Vlasis G. Mavrantzas, University of Patras, Department of Chemical Engineering and FORTH-ICE/HT, Greece

1. Introduction

iv

344

303

- 2. Molecular simulations
- 3. The concept of amorphous cell and of the molecular model
- 4. The molecular dynamics method
 - 4.1. Higher-Order (Gear) Methods
 - 4.2. Verlet Methods
 - 4.3. MD in the NVT Statistical Ensemble
 - 4.4. MD in the NPT Statistical Ensemble
 - 4.5. Multiple Time Step Algorithms The Rrespa Algorithm
 - 4.6. Parallel MD
 - 4.7. Examples
- 5. The Monte Carlo method
 - 5.1. Typical Monte Carlo Moves
 - 5.2. More Complex MC Moves
 - 5.3. Acceptance Criterion Simulation Details
 - 5.4. An Example: MC Simulation of An Alkanethiol-Au(111) Self-Assembled Monolayer
- 6. The dissipative particles dynamics (DPD) method
 - 6.1. Equations of Motion in DPD
 - 6.2. An Example DPD Simulation of a Lipid Bilayer Model
- 7. Conclusion

Index

About EOLSS

VOLUME II

Evaporation And Condensation

J. Mikielewicz, Institute of Fluid Flow Machinery Polish Academy of Sciences, Gdańsk, Poland D. Mikielewicz, Gdańsk University of Technology, Faculty of Mechanical Engineering, Poland

1. Introduction

- 2. Pool Boiling
 - 2.1. Bubble Formation, Growth and Departure
 - 2.2. Pool Boiling Heat Transfer
 - 2.3. Pool Boiling Crisis
- 3. Flow Boiling
 - 3.1. Hydrodynamics of Two-Phase Flow
 - 3.2. Forced Convection Boiling
 - 3.3. Flow Boiling Crisis
- 4. Thermal-hydraulic Phenomena during Flow Boiling in Small Diameter Channels
- 5. Condensation
 - 5.1. Film Condensation
 - 5.1.1. Laminar Motion of Condensate
 - 5.1.2. Turbulent Motion of Condensate
 - 5.2. Condensation on Tubes
 - 5.2.1. Condensation on Tube Banks
 - 5.3. Effect of Noncondensable Gas
 - 5.4. Condensation inside Tubes

Refrigeration

D. Mikielewicz, Gdańsk University of Technology, Faculty of Mechanical Engineering, Poland J. Mikielewicz, Institute of Fluid Flow Machinery, Polish Academy of Sciences, Gdańsk, Poland

1. Introduction

2. Methods of refrigeration

v

39

389

395

- 2.1. Non-cyclic Refrigeration
- 2.2. Cyclic Refrigeration
 - 2.2.1. Carnot Cycle
 - 2.2.2. Lorenz Cycle
 - 2.2.3. Vapor-compression Cycle (VCC) Linde Cycle
 - 2.2.2. Vapor Absorption Cycle (VAC)
 - 2.2.3. Gas Cycle
 - 2.2.4. Thermoelectric Refrigeration
 - 2.2.5. Magnetic Refrigeration
 - 2.2.6. Vortex Tube
 - 2.2.7. Thermoacoustic Refrigeration
 - 2.2.8. Steam jet refrigeration (SJR)
 - 2.2.9. Metal Hydride refrigeration
- 3. Refrigerants
 - 3.1. Azeotropic, near Azeotropic and Zeotropic Mixtures
 - 3.1.1. Azeotropic Mixtures
 - 3.1.2. Non-azeotropic Mixture
 - 3.1.3. Near-azeotropic Mixture
 - 3.1.4. Blends
 - 3.1.5. Glide 3.2. Nomenclature used in Refrigeration Notation
 - 3.3. The Greenhouse Effect
 - 3.4. The Montreal Protocol
- 4. New developments in refrigeration technology

Distillation or Rectification

J.G. Stichlmair, Department of Chemical Engineering, Technische Universität München, Germany

68

- 1. Introduction 2.
 - Fundamentals
 - 2.1. Vapor Liquid Equilibrium
 - 2.1.1. Binary Mixtures
 - 2.1.2. **Ternary Mixtures**
 - Multicomponent Mixtures 2.1.3.
 - 2.2. Continuous Distillation Processes
 - **Binary Mixtures** 2.2.1.
 - 2.2.2. **Ternary Mixtures**
 - 2.2.3. Multicomponent Mixtures
 - 2.3. Batch Distillation
 - 2.4. Reactive Distillation
- 3. Equipment
 - 3.1. Tray Columns
 - 3.2. Packed Columns
- 4. Separation Processes
 - 4.1. Processes for Separating Zeotropic Mixtures
 - 4.2. Processes for Separating Azeotropic Mixtures

Mass Transfer Operations - Absorption and Extraction

José Coca, Department of Chemical Engineering and Environmental Technology, University of Oviedo, Oviedo, SPAIN Salvador Ordóñez, Department of Chemical Engineering and Environmental Technology, University of

Oviedo, Oviedo, SPAIN Eva Díaz ,Department of Chemical Engineering and Environmental Technology, University of Oviedo, Oviedo, SPAIN

1. Introduction

- 2. Gas absorption
 - 2.1. Phase Equilibrium
 - 2.2. Gas absorption Calculations
 - 2.2.1. Graphical Methods
 - 2.2.2. Mass Transfer Method
 - 2.2.3. Short-cut Methods
 - 2.3. Absorption with Chemical Reaction
 - 2.4. Non-isothermal Absorption
 - 2.5. Absorption Equipment
 - 2.5.1. Packed Towers
 - 2.5.2. Plate Towers
 - 2.5.3. Agitated Vessels
 - 2.5.4. Centrifugal Absorbers
 - 2.5.5. Spray Towers
 - 2.6. Absorber Design and Costs: Rules of Thumb
 - 2.7. Systematic Procedure for Design of an Absorber
- 3. Liquid-liquid Extraction
 - 3.1. Phase Equilibrium
 - 3.2. Liquid-liquid Extraction Calculations
 - 3.2.1. Graphical Methods
 - 3.2.2. Mass-transfer Method
 - 3.2.3. Short-cut Methods
 - 3.3. Extraction Equipment
 - 3.3.1. Mixer-settlers
 - 3.3.2. Column Contactors
 - 3.3.3. Centrifugal Extractors
 - 3.3.4. Membrane Extractors
 - 3.4. Extractor Design and Costs: Rules of Thumb

Mass Transfer Operation - Membrane Separations

Enrico Drioli, Institute on Membrane Technology Efrem Curcio, ITM-CNR, c/o University of Calabria, Rende (CS), Italy Department of Chemical Engineering and Materials Enrica Fontananova, University of Calabria, Rende (CS), Italy

- 1. Introduction
- 2. An overview on the most industrialized membrane separation processes and emerging applications
 - 2.1. Pressure driven membrane processes
 - 2.1.1. Reverse osmosis
 - 2.1.2. Nanofiltration
 - 2.1.3. Ultrafiltration
 - 2.1.4. Microfiltration
 - 2.2. Electrodialysis
 - 2.3. Gas separation
 - 2.4. Pervaporation and vapor permeation
 - 2.5. Membrane contactors
 - 2.5.1. Membrane distillation
 - 2.5.2. Membrane crystallization
 - 2.5.3. Membrane emulsification
 - 2.6. Catalytic membranes reactors
- 3. Sustainable growth and integrated membrane operations
 - 3.1. Case study 1: Membrane technology in desalination
 - 3.2. Case study 2: Membrane technology in fruit juices industry
 - 3.3. Case study 3: Membrane technology for wastewaters treatment in the leather industry
- 4. Conclusions

Mass Transfer Operations: Hybrid Membrane Processes

E. Drioli, E. Curcio, E. Fontananova, National Research Council of Italy, Institute on Membrane Technology (ITALY) Department of Chemical Engineering and Materials, University of Calabria (ITALY)

- 1. Introduction
- 2. Hybrid Membrane Desalination Systems
 - 2.1. MSF/RO Systems
 - 2.2. NF/MSF Systems
 - 2.3. MF and UF as Pretreatment Processes
- 3. Integrated membrane systems in agrofood industry
- 4. Hybrid membrane operations for wastewater treatment
- 5. Integrated membrane operations in Gas Separation
- 6. Integration of molecular separation and chemical/energy conversion
 - 6.1. Catalytic Membrane Reactors
 - 6.2. Fuel Cells
- 7. Conclusions

Handling Of Fluids

B.J. Azzopardi, Faculty of Engineering, University of Nottingham, Nottingham, UK

220

- 1. Introduction
- 2. Storage
 - 2.1 Bunding
 - 2.2 Breathing
 - 2.3 Filling and emptying
 - 2.4 Boiling-liquid expanding-vapour explosion (BLEVE)
- 3. Transportation
- 4. Pumping
 - 4.1 Basics
 - 4.2 Liquids
 - 4.3 Gases
- 5. Metering
 - 5.1 Pressure difference devices
 - 5.2 Variable area meters
 - 5.3 Vortex shedding
 - 5.4 Turbine meter
 - 5.5 Ultrasonic meter
 - 5.6 Magnetic meter

Heat and Mass Transfer Operations - Crystallization

J. Ulrich, TVT, Martin-Luther-Univ. Halle-Wittenberg, Germany M.J. Jones, TVT, Martin-Luther-Univ. Halle-Wittenberg, Germany

1. Introduction

- 2. Solid-Liquid-Equilibria
 - 2.1. Solubilities and Phase Diagrams
 - 2.2. The Metastable Zone
 - 2.3. Phase Diagrams for Melt Crystallization
- 3. Kinetics
 - 3.1. Nucleation
 - 3.2. Crystal growth
- 4. Properties of Crystals
 - 4.1. Crystal Structures
 - 4.2. Crystal Shape (Habit)
 - 4.3. Crystal Size and Crystal Size Distribution

235

- 5. Crystallization Technology
 - 5.1. Solution Crystallization
 - 5.2. Melt Crystallization

Handling of Solids - Transport and Storage

H.J. Feise, Process Engineering, BASF AG, Ludwigshafen, Germany

- 1. Introduction
- 2. History
- 3. Characterization of Bulk Solids
 - 3.1. Particle Properties
 - 3.2. Bulk Solids Properties
 - 3.2.1. Bulk Density Bulk Solid Density
 - 3.2.2. Angle of Repose
 - 3.2.3. Fluidization Properties
 - 3.2.4. Wall Friction
 - 3.2.5. Flow Properties
 - 3.2.6. Lateral Stress Ratio
- 4. Storage of Bulk Solids
 - 4.1. Design of Silos for Flow
 - 4.1.1. Flow Patterns
 - 4.1.2. Flow Problems
 - 4.1.3. Hopper Design
 - 4.1.4. Silo Shapes
 - 4.1.5. Outlet Design
 - 4.2. Design of Silos for Strength
 - 4.2.1. Stress Distribution
 - 4.2.2. Janssen Equation
 - 4.2.3. Design Standards
 - 4.3. Caking of Bulk Solids
 - 4.3.1. The Significance of Time Consolidation
 - 4.3.2. Caking Mechanisms
 - 4.3.3. Formation of Solid Bridges
 - 4.3.4. Solutions to Caking Problems
- 5. Transport
 - 5.1. Modes of Transport
 - 5.2. Pneumatic Conveying
 - 5.2.1. State Diagram of Pneumatic Conveying
 - 5.2.2. Basic Components of a Pneumatic Conveying System
 - 5.3. Screw Feeders and Screw Conveyors
 - 5.3.1. Screw Conveyors
 - 5.3.2. Screw Feeder
 - 5.3.3. Screw Conveyer Feed Rate
 - 5.3.4. Screw Casing

Particle Growth and Agglomeration Processes

R. P. J. Sochon, Particle Products Group, Department of Chemical and Process Engineering, University of Sheffield, UK

A.D. Salman, Particle Products Group, Department of Chemical and Process Engineering, University of Sheffield, UK

- 1. Introduction
- 2. Product properties
- 3. Rate Processes
 - 3.1. Wetting and Nucleation
 - 3.2. Growth and consolidation

- 3.3. Attrition and Breakage
- 4. Regime maps
 - 4.1. Nucleation regime map
 - 4.2. Granulation regime map
- 5. Population Balance equations
- 6. Granulation Equipment
 - 6.1. Drum granulation
 - 6.2. Pan granulation
 - 6.3. Fluidized bed granulation
 - 6.4. High Shear Mixer Granulators
 - 6.5. Dry Granulation
 - 6.5.1. Roll compaction
 - 6.5.2. Direct compression
- 7. Equipment Design
- 8. Conclusion

Index

About EOLSS

VOLUME III

Ideal Models of Reactors

A.Burghardt, Polish Academy of Sciences, Poland

- 1. Introduction
- 2. The Thermodynamic State of a System
- 3. The Plug Flow Reactor
- 4. The Perfectly Mixed Tank Reactor
- 5. The Batch Reactor
- 6. The Cascade of Tank Reactors
- 7. Comparison of Different Types of Reactors
 - 7.1. Size Comparison of Single Reactors
 - 7.2. The Cascade of Tank Reactors
 - 7.3. Multireaction systems

Nonideal Flow Models in Homogeneous Chemical Reactors

Andrzej Burghardt, Institute of Chemical Engineering, Polish Academy of Sciences, Poland

- 1. Introduction
- 2. The Residence Time Distribution (RTD)
 - 2.1. The RTD Functions of Ideal Flows
- 3. Models of Nonideal Flows
 - 3.1. The Axially Dispersed Plug Flow Model
 - 3.1.1. Correlations for Axial Dispersion Coefficients
 - 3.2. The Tanks in Series Model
 - 3.3. The Multiparameter Models
- 4. Influence of Mixing Phenomena on Chemical Reactions
 - 4.1. The Limiting Cases of Conversion
- 5. Example

Multiphase Reactors

A. Stankiewicz, Process & Energy Department, Delft University of Technology, The Netherlands

1. Introduction

90

317

323

1

- 2. Fundamentals of phase contacting in chemical reactors
- 3. Reactor selection and design issues in multiphase reactors
- 4. Basic Types of Multiphase Reactors and their Design Features
 - 4.1. Catalytic Gas-solid Reactors
 - 4.1.1. Fixed-bed Reactors for Adiabatic Operation
 - 4.1.2. Multitubular Fixed-bed Reactors
 - 4.1.3. Fluidized-bed Reactors
 - 4.2. Reactors for Non-catalytic Gas-solid Reactions
 - 4.3. Reactors for Gas-liquid Reactions
 - 4.3.1. Stirred-tank Reactors
 - 4.3.2. Bubble Column Reactors
 - 4.3.3. Gas-lift Reactors
 - 4.3.4. Jet-loop Reactors
 - 4.3.5. Static Mixer Reactors
 - 4.3.6. Thin-film Reactors
 - 4.4. Liquid-liquid Reactors
 - 4.5. Gas-liquid-solid Reactors
 - 4.5.1. Slurry Reactors
 - 4.5.2. Trickle-bed Reactors
 - 4.5.3. Structured-catalyst Reactors
- 5. Future outlook

Catalytic Reactors: A Review

122

V. K. Jayaraman, Chemical Engineering and Process Development Division, National Chemical Laboratory, India

B. D. Kulkarni, Chemical Engineering and Process Development Division, National Chemical Laboratory, India

- Introduction
 Fixed Bed Red
 - Fixed Bed Reactor
 - 2.1. Adiabatic Reactors
 - 2.2. Nonisothermal-Nonadiabatic Tubular Reactor
 - 2.3. Fixed Bed Reactors with Heat Exchangers
 - 2.4. Reverse Flow Tubular Reactor
 - 2.5. Fixed Bed with Two Phase Flow (FBTPF)
 - 2.6. Choice between PBC and TBR
- 3. Fluidized Bed Reactor
 - 3.1. Three Phase Fluidized Bed Reactors
 - 3.2. Heat and Mass Transfer in Fluidized bed
 - 3.3. High Pressure Operation for fluidized bed
- 4. Biocatalytic Reactors
- 5. Unconventional Reactors
 - 5.1. Membrane Reactors
 - 5.2. Photocatalytic Reactor
 - 5.3. Moving Bed and Chromatographic Reactors
 - 5.4. Monolith Reactors
 - 5.5. Reactive Distillation cum Catalytic Reactor (See also Multifunctional Reactors)
 - 5.6. Microstructured Catalytic Reactors (See also Microreactors)
- 6. Conclusion

Polymerization Reactors

J.T.F.Keurentjes, *Eindhoven University of Technology, MB Eindhoven, The Netherlands* Th. Meyer, *Ecole Polytechnique Fédérale de Lausanne, CH-1015, Switzerland*

- 1. Polymers
- 2. A short history of polymer reaction engineering

- 3. Polymerization mechanisms
- 4. Polymerization reactors
 - 4.1. Reactors for Homogeneous Polymerization
 - 4.1.1. The Gel Effect
 - 4.1.2. The Effect of Mixing
 - 4.1.3. Copolymerizations
 - 4.2. Reactors for Emulsion Polymerization
 - 4.2.1. Critical Parameters for Batch Emulsion Polymerization
 - 4.2.2. Thermal Runaway
 - 4.2.3. Control of Particle Size Distribution
 - 4.3. Reactors for Polycondensation
- 5. Towards product-inspired polymer reaction engineering

Electrochemical Reactors

Francois Lapicque, Laboratoire des Sciences du Genie Chimique, CNRS-ENSIC-LSGC, France

160

- 1. Introduction
- 2. Backgrounds of electrochemistry
 - 2.1. Electrode Interface and Double Layer
 - 2.2. Potentials and Currents
 - 2.3. Faraday's Law
 - 2.4. Electrodes and Cells at Equilibrium
 - 2.5. Electrode Overpotential
 - 2.6. Cell Voltage and Yields
- 3. Transport and transfer phenomena in electrochemical processes
 - 3.1. Mass Transport Rates and Current Density
 - 3.2. Mass Transfer to Electrode Surfaces
 - 3.2.1. Transfer Phenomena
 - 3.2.2. The Nernst's Film Model
 - 3.2.3. Mass Transfer Coefficient and Existing Correlations
- 4. Technology of electrochemical reactors
 - 4.1. A typical Cell: the Filter-press Cell
 - 4.1.1. General Aspects
 - 4.1.2. Electrical Connection
 - 4.1.3. Hydraulic Connection
 - 4.2. Other Cell Configurations in Liquid Media
 - 4.2.1. "Pool" or Tank Cells
 - 4.2.2. Use of Turbulence Promoters
 - 4.2.3. Three-dimensional Electrodes
 - 4.2.4. Bipolar Electrode Cells
 - 4.3. Cells for Gas Generation
 - 4.3.1. Water Electrolysis
 - 4.3.2. Chlorine-alkali Electrolysers
- 5. Current distribution in electrochemical cells
- 6. Design of electrochemical cells: an introduction
 - 6.1. General Features
 - 6.2. An Example: The Continuous Filter-press Operated at Limiting Current
- 7. Current trends in electrochemical engineering

Multifunctional Reactors

Kai Sundmacher, Max-Planck-Institute for Dynamics of Complex Technical Systems, Magdeburg, Germany

Zhiwen Qi, Process Systems Engineering, Otto-von-Guericke-University Magdeburg, Germany

- 1. Introduction
- 2. Reactive Separation Processes

- 2.1. Reactive Distillation
 - 2.1.1. Principle
 - 2.1.2. Application Examples
 - 2.1.3. Process Design Issues
 - 2.1.4. Future Directions
- 2.2. Reactive Absorption
 - 2.2.1. Principle
 - 2.2.2. Industrial Applications
 - 2.2.3. Equipment
 - 2.2.4. Application Limitations
- 2.3. Reactive Adsorption
 - 2.3.1. Principle
 - 2.3.2. Reactor Types
 - 2.3.3. Application Examples and Limitations
- 2.4. Reactive Extraction
 - 2.4.1. Principle
 - 2.4.2. Applications
- 2.5. Membrane Reactors
 - 2.5.1. Principle
 - 2.5.2. Application Examples
- 2.6. Reactive Crystallization and Reactive Precipitation
- Mechanical Integrated Processes
- 3.1. Reactive Filtration
 - 3.2. Reactive Comminution
 - 3.3. Reactive Extrusion
- 4. Heat Integrated Processes
 - 4.1. High Temperature Fuel Cells with Fuel Reforming
 - 4.2. Heat-Integrated Processes for Endothermic and Exothermic Reactions
- 5. Conclusions

3.

Microreactors

218

T. Illg, Institut für Mikrotechnik Mainz GmbH, Carl Zeiss Strasse 18 20, 55129 Mainz, Germany V. Hessel, Eindhoven University of Technology, Den Dolech 2, 5600 MB Eindhoven, The Netherlands Institut für Mikrotechnik Mainz GmbH, Carl Zeiss Strasse 18 20, 55129 Mainz, Germany

- 1. Introduction
- 2. General benefits of microreactors
- 3. Selected types of microreactors
 - 3.1. Liquid / Liquid Contactors (Micromixers)
 - 3.1.1. Lamination and Hydrodynamic Focusing
 - 3.1.2. Jet Mixing
 - 3.1.3. Split-and-Recombine Mixing
 - 3.1.4. Recirculation-Flow Mixing In Curved Channels
 - 3.1.5. Recirculation-Flow Mixing In Bas-Relief Mixers
 - 3.1.6. Barrier-Embedded Micromixer
 - 3.1.7. Microreactor with Integrated Mixer
 - 3.1.8. Gas/Liquid Contactors
 - 3.1.9. Falling Film Microreactors
 - 3.1.10. Taylor- and Annular Flow Reactors
 - 3.1.11. Packed Bed Microreactor
 - 3.2. Catalytic Gas-Phase Microreactors
- 4. Selected examples of use
 - 4.1. Liquid/Liquid Reactions
 - 4.1.1. Selective Friedel-Crafts Aminoalkylation
 - 4.1.2. Alkylation
 - 4.1.3. Nitration with High-Energetic Nitrating Agents
 - 4.1.4. Lithiation

- 4.1.5. Selective Oxidation
- 4.1.6. Beta-Peptide Synthesis
- 4.1.7. Radiolabeled Imaging Probe Generation
- 4.2. Gas/Liquid Reactions
 - 4.2.1. Halogenation
 - 4.2.2. Hydrogenation
- 4.3. Catalytic Gas-Phase Reaction
 - 4.3.1. Epoxidation
 - 4.3.2. Partial Oxidation

5. Cost analysis

6. Eco efficiency analysis

7. Process safety

Index

253

257

About EOLSS

VOLUME IV

 Solution of Model Equations
 1

 Ian Thomas Cameron, The University of Queensland, Australia
 1

- 1. Introduction
- 2. Classes of Problems and Computer Methods
- 3. Algebraic Equation Systems
- 3.1. Iterative Methods
 - 3.1.1. One-point iteration methods
 - 3.1.2. Interpolation methods for algebraic equations
- 4. Ordinary Differential Equation Systems
 - 4.1. Single step explicit methods
 - 4.2. Single step implicit methods
 - 4.3. Multistep explicit methods
 - 4.4. Multistep implicit methods
- 5. Differential-Algebraic Equation Methods
 - 5.1. Implicit simultaneous solution of DAEs
 - 5.2. Implicit or explicit structured solutions of DAEs
- 6. Partial Differential Equation Systems (PDEs)
 - 6.1. Finite Difference Methods
 - 6.2. Method of Lines
 - 6.3. Finite element methods
- 7. Optimization Methods
 - 7.1. Function value searching methods
 - 7.2. Function and gradient methods
 - 7.3. Linear programming methods
 - 7.4. Transformation methods
- 8. Conclusion

Process Analysis and Optimization

Luke E. K. Achenie, Department of Chemical Engineering, University of Connecticut, USA Gennady Ostrovsky, Department of Chemical Engineering, University of Connecticut, USA

- 1. Introduction
- 2. Steady State Simulation of a Chemical Process
 - 2.1. Structure of Process Flowsheets
 - 2.2. Process Model Representation of Flowsheet
 - 2.3. Structural Analysis

- 2.3.1. Partitioning
- 2.3.2. Precedence ordering
- 2.3.3. Tearing
- 2.3.4. Example
- 3. Solving a System of Nonlinear Equations
 - 3.1. Newton Method
 - 3.2. Quasi-Newton Method
- 4. Process Optimization
 - 4.1. Unconstrained Optimization
 - 4.2. Constrained Optimization
 - 4.2.1. Langrange Multiplier Method
 - 4.2.2. Penalty Method
 - 4.2.3. The Modified Lagrange Function Method
 - 4.2.4. Sequential Quadratic Programming
- 5. Conclusions

Data Reconciliation

Georges Heyen, Department of Chemical Engineering University of Liege, Belgium

70

- 1. Scope, aims and benefits of Data Reconciliation
 - 1.1. Importance of Measurements for Process Monitoring
 - 1.2. Sources of Experimental Errors
 - 1.3. How to Achieve Measurement Redundancy
- 2. Exploiting redundancy
 - 2.1. Variable Classification
 - 2.2. Benefits of Model Based Data Validation
- 3. Mathematical formulation of the validation problem
 - 3.1. Data Validation for Steady State Systems
 - 3.2. Solution for Linear Systems
 - 3.3. Nonlinear Case
 - 3.4. Reduction of Uncertainty
 - 3.5. Extension to Dynamics
- 4. Applications
 - 4.1. Illustration of the Method
 - 4.2. Monitoring Steam to Carbon Ratio in a Hydrogen Plant
 - 4.3. A Nuclear Power Plant
- 5. Conclusions

Product Centered Process Design

Christianto Wibowo, *ClearWaterBay Technology, Inc., Walnut, CA 91789, U.S.A.* Ka M. Ng, *The Hong Kong University of Science and Technology, Hong Kong* 93

- 1. Introduction
- 2. Systematic Framework for the Manufacture of Chemical-Based Products
- 3. Product Conceptualization
- 4. Identification of Product Quality Factors
- 5. Selection of Ingredients and Product Microstructure
- 6. Generation of Process Alternatives
- 7. Product and Process Evaluation
- 8. Example: Shampoo and Conditioner in One Product
- 9. Conclusions

Development Of Chemical Processes

Herbert Vogel, Ernst-Berl-Institut für Technische und Makromolekulare Chemie, Technische Universität Darmstadt, Germany.

1. Introduction

- 2. Scientific Basics of Process Development
 - 2.1. Physical chemical data
 - 2.2. Thermodynamics
 - 2.3. Chemical Kinetics
 - 2.4. Hydrodynamics
- 3. The Components of a Chemical production Plant
 - 3.1. Catalyst
 - 3.2. Chemical Reactor
 - 3.3. Separation Processes
- 4. Standard Approach of Process Development
 - 4.1. Process Development as an Iterative Process
 - 4.2. Putting up an Initial Version of the Chemical Process
 - 4.3. Testing of the Single Process Steps
 - 4.4. Microplants
 - 4.5. Checking the Integrated Process in a Miniplant
 - 4.5.1. Miniplant Technology
 - 4.5.1.1. Construction of a Miniplant
 - 4.5.1.2. The Limits of Miniaturization
 - 4.5.1.3. Limitations of the Miniplant Technology
 - 4.5.2. The Pilot Plant
- 5. Execution of a Project
- 6. Evaluation of Chemical Processes
 - 6.1. Preparation of Study Reports
 - 6.2. The Evaluation of the Investment
 - 6.3. The Evaluation of the Production Costs
- 7. The Future of the Process Development

Process Safety

R L Skelton, University of Cambridge UK

- 1. Introduction
- 2. Terminology
- 3. Safety Assurance Techniques
- 4. Safety in Design
 - 4.1. Inherent Safety
 - 4.2. Engineered Safety
 - 4.3. Operating Instructions
- 5. HAZOP
 - 5.1. Introduction
 - 5.2. The Basic Concept
 - 5.3. HAZOP Definitions
 - 5.4. Study Team
 - 5.5. Timing of the Study
 - 5.6. Documentation
 - 5.7. Conduct of Study
 - 5.8. Reporting
 - 5.9. Action control & Follow up
 - 5.10. Conclusions
- 6. Quantitative Risk Assessment
 - 6.1. Definitions
 - 6.2. Fault Tree Analysis (FTA)
 - 6.2.1. Common Events
 - 6.2.2. Basic Rules for Logic Tree Construction
 - 6.3. Failure Data
 - 6.3.1. Sources of Data
 - 6.3.2. Analysis of Failure Data
 - 6.4. Quantification Of Logic Diagrams

- 6.4.1. Basic Rules for Combination of Events
- 6.4.2. Fractional Dead Time
- 6.4.3. Common Mode or Dependent Failure Analysis
- 6.4.4. Use of Boolean Algebra
- 6.4.5. Use of Information
- 6.5. Event Tree Analysis
 - 6.5.1. Notation
 - 6.5.2. Event Tree Construction
- 7. Safety in Operation
 - 7.1. Chemical Hazards
 - 7.2. Fires and Explosions
 - 7.2.1. Definitions
 - 7.2.2. Explosion Prevention
 - 7.2.3. Explosion Venting
 - 7.2.4. Fire Fighting
 - 7.3. Other Hazards
 - 7.4. Staff Selection and Training
 - 7.5. Investigation
- 8. Safety in Maintenance
 - 8.1. Permit to Work
 - 8.2. Maintenance Procedures

Process Risk Analysis

W. Witt, Brandenburgische Technical University of Cottbus, Cottbus, Germany N. Ramzan, Brandenburgische Technical University of Cottbus, Cottbus, Germany

- 1. Introduction
- 2. Terminology Used in This Chapter
- 3. Application of safety/risk techniques
- 4. Hazard identification and safety/risk analysis techniques
 - 4.1. Hazard Potential Analysis
 - 4.1.1. Potential Release Estimate
 - 4.2. Matrices
 - 4.2.1. Reaction Matrices
 - 4.2.2. Process Control/Shut Down and Automation Matrices
 - 4.3. Check Lists
 - 4.4. Hazard and Operability Study (HAZOP)
 - 4.5. Failure Mode and Effect Analysis (FMEA)
 - 4.6. Fault Tree Analysis
 - 4.7. Event Tree Analysis
 - 4.8. Acceptable Level of Risk / Decision Techniques 4.8.1. Risk Potential Matrix
- 5. Frequency/Probability Modeling Techniques
 - 5.1. Fundamentals
 - 5.2. Failure Data of Equipment and System
 - 5.2.1. Failure Rate
 - 5.2.2. Failure on Demand
 - 5.3. Calculation of System Failure Probability and Frequency
- 6. Consequence Analysis Techniques
 - 6.1. Source Term
 - 6.1.1. Estimation of Source Area
 - 6.1.2. Release from Plant Equipment
 - 6.1.2.1. Gas / vapor release via short pipe (no friction)
 - 6.1.2.2. Liquid release via short pipe (no friction)
 - 6.1.2.3. Two-phase flow via short pipe (no friction)
 - 6.1.3. Release from Liquid/Liquid Pool
 - 6.1.3.1. Flash Evaporation

- 6.1.3.2. Diffusional Evaporation from a Liquid Pool
- 6.1.3.3. Evaporation from a liquid pool
- 6.2. Dispersion
 - 6.2.1. Neutrally Buoyant Gas
 - 6.2.2. Dense Gas
- 6.3. Effects
 - 6.3.1. Fire Hazards
 - 6.3.1.1. Heat radiation fundamentals
 - 6.3.1.2. Fire scenario, fire ball
 - 6.3.1.3. Consequences of Heat Radiation
 - 6.3.2. Explosion Hazards
 - 6.3.3. Toxic Hazards
- 7. Safety Concepts in Process Development and Plant Design
 - 7.1. General Aspects
 - 7.2. Methods for Safety Concept Definition
 - 7.2.1. Aspects to be Considered
 - 7.2.1.1. ATEX
 - 7.2.1.2. Safety instrument systems (SIS)
 - 7.3. Results
- 8. Safety and Risk Analysis
 - 8.1. Screening/Index Methods
 - 8.1.1. DOW Fire and Explosion Index
 - 8.2. Standard Methods
 - 8.3. Advanced and Extended Methods
 - 8.3.1. Computer Support
 - 8.3.2. Risk Presentation
 - 8.3.3. Disturbance Simulation
 - 8.3.4. Optimization
- 9. Hazard, Safety and Risk Management in Plant Design and Operation
 - 9.1. Major Accident Prevention Program (MAPP)

Recovery And Recycling Of Post-Consumer Waste Materials Jan Baeyens, *University of Warwick, School of Engineering, Coventry, UK*

264

Anke Brems, Association K.U.Leuven - Campus De Nayer, Laboratory of Environmental and Process Technology, Sint-Katelijne-Waver, Belgium

Raf Dewil, Association K.U.Leuven - Campus De Nayer, Laboratory of Environmental and Process Technology, Sint-Katelijne-Waver, Belgium

Katholieke Universiteit Leuven, Department of Chemical Engineering, Heverlee, Belgium

- 1. Introduction
- 2. Recycling: a growing field of sustainable development
- 3. Legislative evaluation
- 4. Recycling: targets, priorities, quality control and marketing
 - 4.1. Targets and Priorities
 - 4.2. Quality Control is Essential in Recycling
 - 4.3. Marketing
- 5. Target post-consumer waste recovery and recycling sectors
- 5.1. Paper and Cardboard
 - 5.1.1. Pulp and Paper & Cardboard Production
 - 5.1.2. Recovery and Recycling
 - 5.1.3. Environment and Sustainability
 - 5.2. Aluminum Cans
 - 5.2.1. Aluminum
 - 5.2.2. Aluminum Beverage Cans
 - 5.2.3. Aluminum Recycling
 - 5.2.4. Recycling Aluminum Beverage Cans
 - 5.2.5. Environmental Impact of Recycling Aluminum Cans

- 5.3. Glass Beverage Bottles
 - 5.3.1. General Overview
 - 5.3.2. Recycling Process
 - 5.3.3. Overview of Melting Furnaces
- 5.4. Plastic
 - 5.4.1. Mechanical Recycling
 - 5.4.2. Feedstock Recycling
 - 5.4.2. Feedstock Recycling
 - 5.4.2.1. Pyrolysis
 - 5.4.2.2. Hydrocracking
 - 5.4.2.3. Gasification
 - 5.4.2.4. Incineration with Energy Recovery
- 5.5. Scrap Metal and Steel Cans
 - 5.5.1. Steel
 - 5.5.2. Steel for Packaging
 - 5.5.3. Steel Beverage Cans
 - 5.5.4. Manufacturing of Steel for Packaging
 - 5.5.5. Recycling Steel Packaging
 - 5.5.6. Environmental Benefits of Steel Packaging
- 5.6. End-of-life Tires (ELT)
 - 5.6.1. Processing of Waste Tires
 - 5.6.1.1. Retreading
 - 5.6.1.2. Granulation
 - 5.6.1.3. Reclaim/de-vulcanization
 - 5.6.1.4. Incineration
 - 5.6.1.5. Pyrolysis/gasification
- 5.7. Batteries
 - 5.7.1. Household-type Batteries
 - 5.7.1.1. Primary batteries
 - 5.7.1.2. Secondary batteries
 - 5.7.1.3. Separation
 - 5.7.1.4. Pyro-metallurgical treatment of primary batteries
 - 5.7.1.5. Pyrolytic treatment of single-use batteries
 - 5.7.1.6. Mercury distillation of button cells
 - 5.7.1.7. Treatment of rechargeable batteries: NiCd and NiMeH
 - 5.7.1.8. Treatment of rechargeable batteries: Li-ion
 - 5.7.2. Lead Acid Battery Recycling
 - 5.7.2.1. Recycling of lead fraction
 - 5.7.2.2. Recycling of the lead sulfate
 - 5.7.2.3. Treatment of the sulfuric acid
 - 5.7.2.4. Treatment of the plastic fraction
- 5.8. Household Hazardous Waste
 - 5.8.1. Definition of Household Hazardous Waste
 - 5.8.2. Household Hazardous Waste Recycling
 - 5.8.3. Environmental Impact of Household Hazardous Waste

Process Economics

C. R. Deddis, BP Exploration Operating Company Ltd., UK

1. Introduction

- 1.1. The Economic Nature of Chemical Processes
 - 1.1.1. Feedstock
 - 1.1.2. Catalyst
 - 1.1.3. Energy
 - 1.1.4. Products
 - 1.1.5. Waste Products
 - 1.1.6. Interactions

- 2. Economic Evaluation of Chemical Process Projects
 - 2.1. Costs of Chemical Process Projects
 - 2.1.1. Capital Investment
 - 2.1.2. Operating Costs
 - 2.2. Revenue and Profits of Chemical Processes
- 3. Economic Evaluation Techniques
 - 3.1. Net Present Value
 - 3.2. Internal Rate of Return
 - 3.3. Payback Period
- 4. Economic Evaluation of a Major Project in Practice
 - 4.1. Cost Estimation
 - 4.2. Accounting for Uncertainty in the Cost Estimate
 - 4.2.1. Nature of Costs for a Single Item
 - 4.2.2. Total Project Cost Estimate Incorporating Uncertainty
 - 4.3. Intangible Considerations
- 5. Economic Evaluation of Modifications to Operating Process Plants
- 6. Optimization of Operating Costs
 - 6.1. Objective Functions for Optimizing Operating Costs
 - 6.2. Operating Constraints
 - 6.3. Optimization Techniques
- 7. Challenges for the Future

Index

About EOLSS

VOLUME V

Chemical Engineering in 2010, QUO VAMUS?

Jean-Claude Charpentier, Laboratoire Réactions et Génie des Procédés CNRS/ENSIC/INPL, Nancy-Université France

- 1. Introduction
- 2. Expectations from modern chemical engineering in the face of challenges.
- 3. A complementary approach in chemical engineering
- 4. The future of Chemical Engineering: Quo vamus?
 - 4.1. Total Multiscale Control of the Process
 - 4.2. Process Intensification
 - 4.3. Manufacturing End-Use Properties: Product Design and Engineering (The Green Product/Process Couple)

4.4.Application of Multiscale and Multidisciplinary Computational Chemical Engineering Modeling and Simulation to Real-Life Situations

5. Conclusion

Chemical Product Design

G.D. Moggridge, Department of Chemical Engineering, Cambridge University, UK E.L. Cussler, Department of Chemical Engineering and Materials Science, University of Minnesota, USA

- 1. Introduction
- 2. Needs
 - 2.1. Example: Using Offshore Wind Energy
- 3. Ideas
 - 3.1. Example: Mining the Tire Mountain
- 4. Selection
 - 4.1. Example: Deciding Which Nappies (Diapers in US speak) to Use

24

337

343

- 5. Product Manufacture
- 5.1. Example: Freon-Free Foam
- 6. Conclusions

Multi-scale Modeling

43

Wei Ge, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Linna Wang, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China

Wei Wang, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Jian Gao, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Jiayuan Zhang, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China China

Hui Zhao, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Feiguo Chen, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China

Ying Ren, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Xiaoxing Liu, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China

Bona Lu, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Shiqiu Gao, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Jinghai Li, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China Mooson Kwauk, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100080, P. R. China

- 1. Introduction
- 2. Multi-Scale Structures in Chemical Engineering
- 3. Approaches to Analyze Multi-Scale Structures
 - 3.1. Averaging Method
 - 3.2. Discrete Method
 - 3.3. Multi-Scale Method
- 4. Descriptive Multi-Scale Methodology
- 5. Correlative Multi-Scale Methodology
- 6. Analytical Multi-Scale Methodology
 - 6.1. EMMS Model A Case Study on Gas-Solid Two-Phase Flow
 - 6.1.1. System Resolution with Respect to Scales and Dominant Mechanisms
 - 6.1.2. Hydrodynamic Constraints in the Original EMMS Model
 - 6.1.3. Variational Criterion
 - 6.1.4. Numerical Solutions
 - 6.1.5. Regime Identification
 - 6.1.6. Physical Implications of the EMMS Model
 - 6.1.7. Integration of the EMMS Model to CFD
 - 6.2. Towards a General Analytical Multi-Scale Approach
 - 6.2.1. Single-Phase Flow
 - 6.2.2. Gas-Liquid Flow and Three Phase Systems
 - 6.2.3. Emulsion Systems
 - 6.2.4. Granular Flow
 - 6.2.5. Reaction-Diffusion Systems
 - 6.2.6. Application in Mass Transfer Problems
 - 6.3. Mathematical Formulation of the Analytical Multi-Scale Methodology
- 7. Applications in Industries
- 8. Prospects

Chemical Engineering Education

David Shallcross, Department of Chemical and Biomolecular Engineering, University of Melbourne, Australia

1. Introduction

2. History

- 2.1. Origins of Formal Education
- 2.2. The First Paradigm Unit Operations
- 2.3. The Second Paradigm Chemical Engineering Science
- 2.4. Developments Since 1990
- 3. Modern Curriculum Content
 - 3.1. Core Chemical Engineering
 - 3.2. Depth and Breadth in Chemical Engineering
 - 3.3. Design Project
 - 3.4. Safety
 - 3.5. Sustainability and Green Engineering
 - 3.6. Generic Skills
- 4. Pedagogical Practices in Chemical Engineering Education
 - 4.1. Passive Learning versus Active Learning
 - 4.2. Collaborative and Cooperative Learning
 - 4.3. Problem Led Learning and Problem Based Learning
- 5. Accreditation
- 6. Concluding Remarks

Polymers

J. M. Piglowski, Faculty of Chemistry, Wroclaw University of Technology, Poland

- 1. Introduction
- 2. Polymer Classification
- 3. Polymer Synthesis
- 4. Physics of Polymers
- 5. Polymer Modification
 - 5.1. Chemical Modification
 - 5.2. Physical Modification
 - 5.3. Polymer Blends
- 6. Challenges and New Trends in Polymer Science
 - 6.1. Polymer Nanocomposites
 - 6.2. Polymer-based DNA-biosensors
 - 6.3. Controlled Radical Polymerizations as Tools for 'Tailoring' Polymers
 - 6.4. Polymer Synthesis and Modification in Supercritical Carbon Dioxide (scCO₂) Towards "Green Chemistry" of Polymers

Ammonia And Fertilizers

H. Górecki, Institute of Inorganic Technology and Mineral Fertilizer, Wrocław University of Technology, ul. Smoluchowskiego 25, 50-372 Wrocław, Poland

1. Introduction

- 1.1. Role of Fertilizers and Fertilization
- 1.2. Definition of Fertilizers
- 1.3. History of Fertilization and Fertilizers.
- 1.4. Classification of Fertilizers
- 2. Fertilizer raw materials
 - 2.1. Raw Materials for Ammonia Production
 - 2.2. Raw Materials for Phosphate Fertilizer Production
 - 2.3. Potassium Mineral Raw Material
- 3. Fertilizer processes
 - 3.1. Ammonia
 - 3.2. Urea
 - 3.3. Ammonium Nitrate and Calcium Ammonium Nitrate
 - 3.4. Ammonium Sulfate (AS)
 - 3.5. Superphosphates

101

- 3.6. Multicomponent Compound Fertilizers
- 3.7. Mixed Fertilizers in Bulk-blending Form
- 3.8. Fluid Fertilizers
 - 3.8.1. Anhydrous Ammonia and Aqueous Ammonia
 - 3.8.2. Clear Liquid Fertilizer Solution
 - 3.8.3. Suspension Fertilizers
 - 3.8.4. Major Advantages of Fluid Fertilizers
- 3.9. Foliar Fertilizers
- 3.10. Controlled-release Fertilizers
- 3.11. Fertilizer for Special Applications
 - 3.11.1. Hydroponic
 - 3.11.2. Fertigation
- 4. Fertilizers and environment
 - 4.1. Fertilizer Production and Environment
 - 4.2. Fertilizer Use and Environment

Pigments And Dyestuffs

165

J. Hoffmann, Institute of Inorganic Technology and Mineral Fertilizers, Wrocław University of Technology, Poland

A. Puszyński, Institute of Organic and Polymer Technology, Wrocław University of Technology, Poland

- 1. Introduction
 - 1.1. History
 - 1.2. Definitions
 - 1.3. Notion of Color
 - 1.4. Physical Basis of Color Theory
- 2. Pigments
 - 2.1. General Description
 - 2.2. Effect of the Physical Properties of Pigments on Color
 - 2.3. Methods of Dispergating Pigments
 - 2.4. Methods of Dyeing Spun Fibers
- 3. Inorganic pigments
 - 3.1. Titanium White
 - 3.2. Carbon Black
 - 3.3. Iron Oxide Pigments
 - 3.4. Chromium Pigments
 - 3.5. Complex Inorganic Colored (CIC) Pigments
 - 3.6. Pigments Based on Zinc sulfide and Barium Sulfate
 - 3.7. Other Inorganic Pigments
- 4. Organic pigments
 - 4.1. General Information on Organic Pigments
 - 4.2. Classification and Examples of Organic Pigments
- 5. Dyes
 - 5.1. Formation of Dye Colors
 - 5.2. Dye Nomenclature
 - 5.3. Classification of Dyes According to Their Chemical Structure
 - 5.4. Principal Chemical Dyes
 - 5.5. Survey of Main Groups of Commercial Dyes
 - 5.5.1. Direct Dyes
 - 5.5.2. Metal Complex Dyes
 - 5.5.3. Mordant Dyes
 - 5.5.4. Ice Dyes
 - 5.5.5. Vat Dyes
 - 5.5.6. Oxidized Dyes
 - 5.5.7. Reactive Dyes
 - 5.5.8. Dispersed Dyes
 - 5.5.9. Fatty Dyes

5.5.10. Polymer Dyes

6. Recent developments and future trends

Fermentation Products

Katarzyna Chojnacka, Institute of Inorganic Technology and Mineral Fertilizers, Wrocław University of Technology, Poland

- 1. Introduction
 - 1.1. Definition
 - 1.2. History
 - 1.3. Theory
 - 1.4. Benefits and Pitfalls of Fermentation
 - 1.5. Effect on Foods
- 2. Fermentation feedstocks
 - 2.1. Microorganisms
 - 2.2. Nutrient Sources
 - 2.3. Equipment and Conditions of Fermentation
- 3. Food fermentation products
 - 3.1. Milk Products
 - 3.1.1. Curdled Milk
 - 3.1.2. Sour Cream
 - 3.1.3. Yogurt
 - 3.1.4. Kefir
 - 3.1.5. Koumiss
 - 3.1.6. Cheese
 - 3.2. Vegetables
 - 3.2.1. Sauerkraut
 - 3.2.2. Pickles
 - 3.2.3. Olives
 - 3.3. Starchy Plant Foods Cereals, Tubers and Roots
 - 3.3.1. Cereals
 - 3.3.2. Roots and Tubers
 - 3.3.3. Breadmaking
 - 3.4. Proteinaceous Leguminous Seeds and Oil Seeds
 - 3.4.1. Soy Products
 - 3.4.2. Nuts
 - 3.4.3. Cocoa and Coffee
 - 3.5. Meat and Fish Products
 - 3.5.1. Meat
 - 3.5.2. Fish
 - 3.6. Alcoholic Beverages
 - 3.6.1. Fermented, not-distilled
 - 3.6.2. Fermented, distilled
 - 3.7. Vinegar and Other Food Acids
 - 3.7.1. Vinegar
 - 3.7.2. Citric Acid
 - 3.7.3. Tartaric Acid
 - 3.7.4. Fumaric Acid
 - 3.7.5. Lactic Acid
 - 3.8. Oils
- 4. Chemicals and pharmaceuticals made by fermentation
 - 4.1. Ethanol
 - 4.2. Other than Ethanol Industrial Alcohols
 - 4.3. Industrial Enzymes
 - 4.4. Pharmaceuticals
 - 4.4.1. Produced by Direct Fermentation
 - 4.4.2. Produced by Biotransformation
 - 4.4.3. Vitamins

- 4.5. Biopolymers
- 4.6. Flavor Modifiers
 - 4.6.1. Monosodium Glutamate (MSG)
 - 4.6.2. Maltol and ethyl Maltol
 - 4.6.3. Secondary Metabolites
- 5. Fermentation products in feed and agriculture
 - 5.1. Silage
 - 5.2. Microbial Pesticides
 - 5.3. Single Cell Protein (SCP)
- 6. Recent developments and future trends

Engineering Aspects Of Food Processing

P.P. Lewicki, Warsaw University of Life Sciences (SGGW), Warsaw, Poland The State College of Computer Science and Business Administration in Lomza, Poland

- 1. Introduction
- 2. Food industry
- 3. Food processing
 - 3.1. Mechanical Processes
 - 3.1.1. Cleaning of Raw Material
 - 3.1.2. Removal of Inedible Parts
 - 3.1.3. Disintegration
 - 3.1.4. Sorting and Grading
 - 3.1.5. Liquid Expression
 - 3.1.6. Filtration
 - 3.1.7. Application of Centrifugal Force
 - 3.1.8. Mixing
 - 3.1.9. Other Mechanical Processes
 - 3.2. Heat Transfer Processes
 - 3.2.1. Tubular Heat Exchangers
 - 3.2.2. Plate Heat Exchangers
 - 3.2.3. Extended Surface Heat Exchangers
 - 3.2.4. Heat Exchangers of Special Design
 - 3.3. Mass Transfer Processes
 - 3.3.1. Dehydration
 - 3.3.2. Extraction
 - 3.3.3. Crystallization
 - 3.3.4. Distillation
 - 3.3.5. Air Conditioning
 - 3.4. Materials Handling
 - 3.5. Hygiene of Processing
 - 3.6. Food Engineering
- 4. Concluding remarks

Index

About EOLSS

251 257

1

219

VOLUME VI

Rheology

Crispulo Gallegos, Complex Fluid Engineering Laboratory. Departamento de Ingeniería Química. University of Huelva. 21071 Huelva, Spain Kenneth Walters, Institute of Mathematical and Physical Sciences, Aberystwyth University, U.K.

1 What is Rheology?

2. The major components of rheology discussed in this book

- 2.1. Basic concepts on Rheology: an overview
- 2.2. Rheometry
- 2.3. Rheological materials
- 2.4. Rheological processes
- 2.5. Theoretical rheology
- 3. Conclusion

History Of Rheology

Kenneth Walters, Institute of Mathematical and Physical Sciences, Aberystwyth University, U.K.

- 1. Introduction
- 2. Early departures from the classical extremes
- 3. 1890 1940
- 4. 1940 1950
- 5. 1950 1960
- 6. 1960 1970
- 7. 1970 1980
- 8. What of the future?

Continuum Mechanics As A Ground For Rheology

Malkin Alexander Ya, Institute of Petrochemical Synthesis, Russian Academy of Sciences, 117912, Moscow, Leninskii prospect, 29, Russia

- 1. Introduction
- 2. Stresses
 - 2.1. General Theory Introduction
 - 2.2. Law of Equality of the Conjugated Stresses
 - 2.3. Principal Stresses
 - 2.4. Invariants of a Stress Tensor
 - 2.5. Shear
 - 2.6. Hydrostatic Pressure Spherical Tensor and Deviator
 - 2.7. Uniaxial Extension
- 3. Deformations
 - 3.1. Deformations and Displacement
 - 3.1.1. Deformations
 - 3.1.2. Displacements
 - 3.2. Infinitesimal Deformations Principal Values and Invariants
 - 3.3. Large (Finite) Deformations
 - 3.4. Special Cases of Deformations Uniaxial Elongation and Simple Shear
 - 3.4.1. Uniaxial Elongation and Poisson's Ratio
 - 3.4.2. Simple Shear and Pure Shear
- 4. Kinematics of deformations
 - 4.1 Rates of Deformation and Vorticity
 - 4.2. Deformation Rates when Deformations are Large
- 5. Solving problems in continuum mechanics
 - 5.1. Equilibrium (Balance) Momentum Equations
 - 5.2. Conservation of Mass
 - 5.3. Conservation of Energy
 - 5.4. Principles of Formulation of Constitutive Equations
- 6. A review of main conceptions in continuum mechanics

15

The Newtonian Fluid

José M^a Franco, Dept. Ingeniería Química. Facultad de Ciencias Experimentales. Universidad de Huelva. Campus de "El Carmen". 21071 Huelva. Spain Pedro Partal, Dept. Ingeniería Química. Facultad de Ciencias Experimentales. Universidad de Huelva. Campus de "El Carmen". 21071 Huelva. Spain

1 Introduction

- 2. Newton's law of viscosity
 - 2.1. The Principia Mathematica
 - 2.2. The Viscosity Concept
 - 2.3. The 3-D Newton's Law
 - 2.4. Requisites of Newtonian Fluids
- 3. Newtonian Fluid Mechanics
 - 3.1. The Equation of Continuity
 - 3.2. The Equation of Motion
- 4 Estimation of viscosity: temperature and pressure dependence
 - 4.1. Estimation of Gas Viscosity
 - 4.2. Estimation of Liquid Viscosity

The Non-Newtonian Fluid

96

120

74

Pedro Partal, Dept. Ingeniería Química. Facultad de Ciencias Experimentales. Universidad de Huelva. Campus de "El Carmen". 21071 Huelva. Spain José M^a Franco, Dept. Ingeniería Química. Facultad de Ciencias Experimentales. Universidad de Huelva. Campus de "El Carmen". 21071 Huelva. Spain

- 1. General Classification of Solids and Fluids
- 2. Steady State Viscous Behavior
 - 2.1. Shear Thinning/Thickening and Structured Fluids
 - 2.2. Viscoplastic Fluids
 - 2.3. Modeling of the Steady-state Shear Flow
- 3. Time-dependent Viscous Behavior
 - 3.1. Phenomenology of Thixotropy and Rheopexy
 - 3.2 Modeling of Thixotropy
- 4. Yield Stress

Linear Viscoelasticity

Críspulo Gallegos and Francisco J. Martínez Boza, *Complex Fluid Engineering Laboratory*, *Departamento de Ingeniería Química. University of Huelva. 21071 Huelva, Spain*

- 1. Introduction
- 2. The Boltzmann superposition principle
- 3. Derivative models for the relaxation modulus
- 4. Relaxation spectrum
- 5. Small strain material functions
 - 5.1. Stress relaxation
 - 5.2. Creep
 - 5.3. Small Amplitude Oscillatory Shear

6. Calculations of the linear relaxation and retardation spectra from experimental linear viscoelasticity functions

- 6.1. Calculation Of The Linear Relaxation And Retardation Spectra From G(t) And J(t)
 - 6.1.1. Transform Inversion Methods
 - 6.1.2. The Method of Ferry and Williams
- 6.2. Calculation of Relaxation and Retardation Spectra from Harmonic Responses
 - 6.2.1. Transform Inversion Methods
 - 6.2.2. The Method of Ferry and Williams
- 6.3. Least Squares Method

- 6.4. Regularization Method
 - 6.4.1. Calculation of H(λ) from G'(ω)
 - 6.4.2. Calculation of H(λ) from G (ω)
 - 6.4.3. Calculation of $L(\tau)$ from J(t)

Non-Linear Viscoelasticity

J. M. Dealy, Department of Chemical Engineering, McGill University, Montreal, Canada

- 1. Introduction
- 2. A Continuum Mechanics Description of Nonlinear Phenomena
- 3. Molecular Theories of Viscoelasticity
 - 3.1. The Rouse-Bueche Model for Unentangled Polymers
 - 3.2. Entanglement Effects
- 3.3. The Doi-Edwards Model for Entangled Polymers
- 4. A Tube Model Interpretation of Nonlinear Phenomena
 - 4.1. Chain Retraction and the Damping Function
 - 4.2. Convective Constraint Release and Shear Thinning
- 5. Nonlinear Stress Relaxation
 - 5.1. Doi Edwards Prediction and Measurements of the Damping Function
 - 5.2. Normal Stress Relaxation
- 6. Stress Growth and Relaxation in Steady Shear and other Transient Shear Tests
- 7. The Viscometric Functions
 - 7.1. Dependence of Viscosity on Shear Rate
 - 7.2 Effect of Molecular Structure on Viscosity
 - 7.3 Normal Stress Differences in Steady Simple Shear
- 8. Experimental Methods for Shear Measurements
 - 8.1. Generating Step Strain
 - 8.2. Rotational Rheometers
 - 8.3. Sliding Plate Rheometers
 - 8.4. Capillary and Slit Rheometers
- 9. Extensional Flow Behavior
 - 9.1. Introduction
 - 9.2. Extensional Flow Behavior of Melts and Concentrated Solutions
 - 9.2.1. Linear, Monodisperse Polymers
 - 9.2.2. Effect of Polydispersity
 - 9.2.3. Linear Low-Density Polyethylene
 - 9.2.4. Effect of Long-Chain Branching
 - 9.2.5. Randomly Branched Polymers and LDPE
- 10. Experimental Methods for Extensional Flow
 - 10.1. Basic Techniques
 - 10.2 Approximate Methods

Constitutive Modeling of Viscoelastic Fluids

Faith A. Morrison, Department of Chemical Engineering, Michigan Technological University, Houghton, MI USA

- 1. Introduction
- 2. Fluid Mechanics Basics of Rheology
 - 2.1. Conservation Equations
 - 2.2. Constitutive Equations
 - 2.3. Newtonian Fluids
 - 2.4. Non-Newtonian Fluids
- 3. Inelastic Models
 - 3.1. Power-Law Model
 - 3.2. Carreau-Yassuda Model
 - 3.3. Other Models
- 4. Linear-Viscoelastic Models

144

- 4.1. Maxwell Model
- 4.2. Generalized Maxwell Model
- 4.3. Generalized Linear-Viscoelastic Model
- 5. Nonlinear-Viscoelastic Models
 - 5.1. Infinitesimal Strain Tensor
 - 5.2. Upper-Convected Maxwell Model/Lodge Model
 - 5.3. Models Incorporating Other Strain Measures
 - 5.4. Other Types of Nonlinearities
- 6. Conclusion

Computational Rheolgy

205

247

M.F. Webster, H.R. Tamaddon-Jahromi, and F. Belblidia, *Institute of non-Newtonian Fluid Mechanics - Wales, School of Engineering, Swansea University, Singleton Park, SA2 8PP, Swansea, UK*

- 1. Introduction
- 2. Flow and governing equations
- 3. Numerical discretization generalization and a local scheme
- 4. The contraction flow benchmark
 - 4.1. Advance through Experimental Investigation
 - 4.2. Progress and Application through Numerical Methods
 - 4.3. Some Analytical and Semi-analytical Developments
- 5. Specific applications topical case studies
 - 5.1. Modeling of Some Transient Flows
 - 5.2. Pom-pom (Kinetic-based) Modeling
 - 5.2.1. Some Steady-state SXPP Solutions
 - 5.3. Pressure Drop Estimation in Contraction Flows
 - 5.4. Compressible-viscoelastic Flow Modeling
- 6. Conclusions

Time-Dependent Behavior of Solid Polymers

Igor Emri, Center for Experimental Mechanics, University of Ljubljana, Ljubljana Slovenia, and Institute for Sustainable Innovative Technologies, Ljubljana, Slovenia

1. Introduction

- 1.1. Time Dependence
- 1.2. Rheodictic and Arrheodictic Behavior
- 1.3. Time-Dependent Response
 - 1.3.1. Viscoelastic Functions
 - 1.3.2. Viscoelastic Constants
- 2. Rheological Models
 - 2.1. The Maxwell and Voigt Models
 - 2.2. The Voigt Model
 - 2.3. The Models of the Standard Linear Solid
 - 2.4. The Wiechert Model
- 3. Material Functions Expressed in Terms of Relaxation and Retardation Spectra
 - 3.1. The Standard Response Functions in Terms of the Continuous Spectra
 - 3.2. The Standard Response Functions in Terms of the Line Spectra
- 4. Determination of Discrete Spectra Using the Windowing Algorithm
 - 4.1. Definition of the Window
 - 4.2. The Algorithms for the Time-Domain Material Functions
 - 4.3. The Algorithms for the Frequency-Domain Material Functions
 - 4.3.1 The Algorithms for the Storage Functions
 - 4.3.2. The Algorithms for the Loss Functions
 - 4.4. The Algorithms in Presence of Major Experimental Errors
- 5. Material Characterization
 - 5.1. Response to Step-Function Input

- 5.1.1. Specific Constitutive Responses (Isotropic Solids)
- 5.2. Response to Harmonic Excitation
- 6. Interrelations between frequency- and time-domain material functions
- 7. Mixed Uniaxial Deformation/Stress Histories
- 8. Effect of Temperature and Pressure
- 9. The Effect of Moisture and Solvents on Time-Dependent Behavior
- 10. CEM Measuring System
 - 10.1. The Relaxometer
 - 10.2 The Dilatometer

Rheometry

327

Howard A. Barnes, Institute of Mathematics and Physics, Aberystwyth University, Wales, UK, SY23 3BZ João M. Maia, Department of Macromolecular Science and Engineering, Case Western Reserve University, 2100 Adelbert Rd., Cleveland, OH 44106-7202, USA

- 1. Introduction
- 1.1. Rheometers
- 2. Basic Definition of Shear and Extensional Flows
- 3. Measurement of Viscosity
 - 3.1. The Realization of 'Simple' Flow Geometries in Viscosity Measurement
 - 3.1.1. Small-angle Cone and Plate and Small-gap Concentric Cylinder Geometries
 - 3.2. Non-simple but Manageable Viscometer Geometries
 - 3.2.1. Wide-gap Concentric Cylinders
 - 3.2.2. The Rotating Parallel-Plate Viscometer
 - 3.2.3. Pipe/Tube Viscometer
- 4. Viscoelastic Measurements at Small Stresses/Strains
 - 4.1. Oscillatory Testing
 - 4.2. Creep Testing
- 5. Viscoelastic Measurements At Large Stresses/Shear Rates
- 6. Stress or Strain Controlled Rheometers?
- 7. Fluid and Machine Inertial Problems in Shear Rheometry
- 8. Extensional Rheometry
 - 8.1. Uniaxial Extension
 - 8.1.1. Simple Extension
 - 8.1.2. Capillary Break-Up
 - 8.2. Multiaxial Extension
 - 8.2.1. Biaxial Extension
 - 8.2.2. Planar Extension
 - 8.3. Extensional Indexers
 - 8.3.1. Fiber-spinning
 - 8.3.2. Contraction Flows
 - 8.4. Comparison between Different Extensional Rheometer/Indexers
- 9. Some Current Commercial Rheometers

Rheo-Physical and Imaging Techniques

359 Peter Van Puyvelde, Christian Clasen, Paula Moldenaers, and Jan Vermant, K.U. Leuven, Department of Chemical Engineering, W. de Croylaan 46, B-3001 Leuven, Belgium

- 1. Introduction
- 2. Polarimetry
 - 2.1. Definitions
 - 2.2. Experimental Techniques
 - 2.3. Linear Birefringence Measurements: Case-Studies
 - 2.3.1. The Stress-Optical Relation in Polymers
 - 2.3.2. Separation of the Intrinsic and Form Birefringence
 - 2.4. Linear Conservative Dichroism: Case-studies
 - 2.4.1. Immiscible Polymer Blends

- 2.4.2. Filled Polymeric Systems
- 2.5. Conclusion
- 3. Light scattering
 - 3.1. Theoretical Background
 - 3.2. Experimental Set-ups
 - 3.3. Small Angle Light Scattering: Case-studies
 - 3.3.1. Immiscible Polymer Blends
 - 3.3.2. Filled Polymeric Systems
 - 3.3.3. Flow-induced Crystallization of Polymers
 - 3.4. Conclusion
- 4. Direct imaging methods
 - 4.1. Optical Microscopy
 - 4.2. Conclusion
- 5. General conclusion

High Pressure Rheology

Francisco J. Martínez Boza and Críspulo Gallegos, *Complex Fluid Engineering Laboratory*, *Departamento de Ingeniería Química University of Huelva, Huelva, Spain*.

1. Introduction

- 2. Experimental techniques for high-pressure rheology
 - 2.1. Viscometers and Rheometers for High Pressure Rheology
 - 2.1.1. Capillary Viscometers
 - 2.1.2. Rotational Rheometers
 - 2.1.3. High-pressure Sliding Plate Rheometer
 - 2.1.4. Falling Ball and Rolling Ball Viscometers
 - 2.1.5. Falling Cylinder Viscometers
 - 2.1.6. Vibrating Wire Viscometer
 - 2.1.7. Diamond Anvil Cell
 - 2.2. High-pressure Equipments
- 3. Models for high-pressure rheology
 - 3.1. Empirical Models
 - 3.2. Free Volume Models
 - 3.3. Friction Theory Models
- 4. High-pressure rheology applications

Interfacial Rheology

Kasper Masschaele, Steven Vandebril and Jan Vermant, Department of Chemical Engineering, Katholieke Universiteit Leuven, Belgium Basavaraj Madivala, Department of Chemical Engineering, University of Delaware, USA

- 1. Introduction
- 2. Interfacial Rheometry
 - 2.1. Indirect Interfacial Shear Viscometers
 - 2.2. Direct Interfacial Shear Rheometers
 - 2.2.1. Knife-edge Surface Viscometer
 - 2.2.2. Disk Surface Geometry
 - 2.2.3. Bi-cone and Double Wall-Ring Geometries.
 - 2.2.4. Magnetic Rod Surface Viscometer
 - 2.3. Interfacial Dilatational Rheology
- 3. High interface systems and the importance of surface rheology
 - 3.1. Emulsion and Foam Stability
 - 3.2. Lung Surfactants
- 4. Two dimensional systems as platforms for flow visualization
 - 4.1. Two Dimensional Complex Flow Fields

xxxi

414

4.2. Practical Examples of 2D Flow Experiments. 4.2.1. Yielding and Flow of Suspensions 4.2.2. Microfluidics at Interfaces.

5. Conclusion

Index

About EOLSS

VOLUME VII

Non-Newtonian Fluid Mechanics

Kenneth Walters, Institute of Mathematical and Physical Sciences, Aberystwyth University, Aberystwyth, UK.

- 1. Introduction
- 2. The various strands of research activity in non-Newtonian fluid mechanics.
- 3. Rheometry.
- 4. Constitutive modeling.
- 5. Solution of rheological flow problems.
- 6. The flow of elastic fluids in complex geometries experimental.
- 7. Comparison of theory and experiment in non-Newtonian fluid mechanics.

Mixer-Type Rheometry

Lionel Choplin and Philippe Marchal, Centre de Génie Chimique des Milieux Rhéologiquement Complexes (GEMICO), Ecole Nationale Supérieure des Industries Chimiques (ENSIC), Institut National Polytechnique de Lorraine (INPL), Nancy-Université, 1, rue Grandville – BP 20451 – 54001-NANCY Cedex, France.

- 1. Introduction
- 2. Couette Analogy
- 3. Mixer-type rheometry applications
 - 3.1. Cosmetic Lotion Production
 - 3.2. Hydration and Setting of Cement Pastes
 - 3.3. Consolidated Bitumen
 - 3.4. Dynamic Catastrophic Inversion Phase in Emulsions
 - 3.5. Semi-batch Preparation of Concentrated Dispersions

Non-Newtonian Heat Transfer

F. T. Pinho and P. M. Coelho, CEFT/DEMec, Faculdade de Engenharia, Universidade do Porto, Portugal

- 1. Introduction
- 2. Governing Equations
- 2.1. Equations for Pipe Flow
- 3. Boundary and Initial Conditions
- 4. Integral Energy Balances
- 5. Non-Dimensional Numbers
 - 5.1. Definitions of Reynolds and Prandtl Numbers
 - 5.2. Newton's Law of Convection and the Nusselt Number
 - 5.3. The Friction Factor
- 6. Fluid Properties
- 7. Laminar Flow
 - 7.1. Fully-developed Pipe Flow of Purely Viscous Fluids
 - 7.2. Developing Pipe Flow for Purely Viscous Fluids

32

52

439

445

7.3. Laminar Flow of Viscoelastic Fluids and Viscous Dissipation Effects

- 7.3.1. The Brinkman Number
- 7.3.2. Fully Developed Flow for Viscoelastic and Purely Viscous Fluids
- 7.3.3. Thermally Developing Pipe Flow of Viscoelastic Fluids

8. Turbulent Flow

- 8.1. Fully-developed Pipe Flow of Purely Viscous Fluids
 - 8.1.1. Friction Factor
 - 8.1.2. Heat Transfer
- 8.2. Turbulent Flow of Viscoelastic Fluids
 - 8.2.1. Asymptotic Regime for Polymer Solutions: Friction Characteristics
 - 8.2.2. Asymptotic Regime for Polymer Solutions: Heat Transfer Characteristics
 - 8.2.3. Asymptotic Regime for Surfactant Solutions: Friction Characteristics
 - 8.2.4. Asymptotic Regime for Surfactant Solutions: Heat Transfer Characteristics
 - 8.2.5. Non-asymptotic Regime for Polymer and Surfactant Solutions
- 8.3. Coupling Between Heat and Momentum Transfer Mechanisms for Viscoelastic Fluids

9. Heat Transfer in Other Fully-Developed Confined Flows

- 10. Combined Free and Forced Convection
- 11. Some Considerations on Fluid Degradation, Solvent Effects and Applications of Surfactants
- 12. Conclusion

Rheology in Materials Engineering

111

João Maia, Department of Macromolecular Science and Engineering, Case Western Reserve University, 2100 Adelbert Rd., Cleveland, OH 44106-7202, USA

José Covas, I3N - Institute for Nanostructures, Nanomodeling and Nanofabrication, Department of Polymer Engineering, University of Minho, 4800-058 Guimarães, Portugal

Bruno de Cindio, University of Calabria, Department of Engineering Modeling, Laboratory of Rheology and Food Engineering, Via P. Bucci, I 87030 Rende (CS), Italy

Domenico Gabriele, University of Calabria, Department of Engineering Modeling, Laboratory of Rheology and Food Engineering, Via P. Bucci, I 87030 Rende (CS), Italy

1. Introduction

2. Materials and Their Properties

2.1. Polymer Materials: Applications and Processability

- 2.1.1. Applications
- 2.1.2. Viscosity Levels
- 2.1.3. Viscoelasticity
- 2.1.4. Thermal Conductivity
- 2.1.5. Crystallinity
- 2.1.6. Molecular Orientation
- 2.1.7. Thermal Stability
- 2.2. Food Materials: Properties and Modeling
- 3. Processing Technologies
 - 3.1. Extrusion
 - 3.2. Injection Molding
 - 3.3. Blow Molding and Thermoforming
- 4. Influence of Rheology on Materials Processing
 - 4.1. The Role of Rheology in Polymer Processing Sequences
 - 4.1.1. Extrusion The Operating Point of the Extruder
 - 4.1.2. Blown Film
 - 4.1.3. Extrusion Blow Molding
 - 4.1.4. Injection Molding
 - 4.2. Effects and Defects of Rheological Origin
 - 4.2.1. Extrudate Swell
 - 4.2.2. Melt Fracture
 - 4.2.3. Sharkskin
 - 4.2.4. Pulsating Flow

- 4.3. The Role of Rheology in Food Processing
- 4.3.1. Cereal Dough Characterization
- 4.3.2. A Rheology Based Approach to Fig Syrup Production
- 5. Process Modeling
 - 5.1. Modeling in Polymer Processing: Thermoforming [Based On Duarte Et Al. (2005)]

5.2. Modeling in Food Processes: Pasta Drying (Based On Migliori Et Al., 2002; Migliori Et Al., 2005a-2005b)

- 6. Novel Applications and Trends
 - 6.1. Processing Technologies
 - 6.2. Advanced Modeling of Food Materials Aerated Systems
 - 6.2.1. Single Bubble Model
 - 6.2.2. Biscuit baking model
 - 6.2.3. Dairy Foam Flow Modeling

7. Conclusions

Polymer Rheology

Paula Moldenaers, Department of Chemical Engineering, K.U.Leuven, 3001 Leuven, Belgium Jan Mewis, Departement of Chemical Engineering, K.U.Leuven, 3001 Leuven, Belgium

193

- 1. Introduction
- 2. Polymer structure
- 3. General rheological behavior of polymers
 - 3.1. Steady State Flow
 - 3.2. Transient Shear Flow
 - 3.3. Oscillatory Flow
 - 3.4. Extensional Flow
 - 3.5. Temperature and Pressure Effects
- 4. Molecular parameters
 - 4.1. Linear Polymers
 - 4.2. Long-chain Branching
- 5. Molecular models
 - 5.1. Dilute Solutions
 - 5.2. Entangled Polymers
 - 5.2.1. Transient Network Models
 - 5.2.2. Reptation Models for Linear Polymers
 - 5.2.3. Reptation Models for Branched Polymers
 - 5.3. Rheological Determination of the Molecular Weight Distribution
- 6. More complex systems: Liquid crystalline polymers
- 7. Conclusion

Suspensions, Emulsions and Foams

Pier Luca Maffettone, Dipartimento di Ingegneria Chimica, Università di Napoli Federico II Piazzale Tecchio 80, 80125 Napoli, Italy Francesco Greco, Istituto di Ricerche sulla Combustione, CNR, Piazzale Tecchio 80, 80125 Napoli, Italy

1. Suspensions

- 1.1. Dilute Systems
- 1.2. Semi-Dilute and Concentrated Systems
- 2. Emulsions
 - 2.1. Single Drop Deformation
 - 2.1.1. Experiments on Single Drops in Newtonian Systems
 - 2.1.2. Theories on Single Drop Dynamics with Newtonian Liquids
 - 2.1.3. Single Drop Dynamics with Non-Newtonian Liquids
 - 2.2. Rheology of Dilute Emulsion
 - 2.2.1. Linear Viscoelasticity of Dilute Emulsions
 - 2.3. Concentrated Systems

- 2.3.1. Co-continuous Morphology
- 3. Foams
 - 3.1. Morphology Dynamics
 - 3.2. Foam Rheology
 - 3.2.1. Solid-like Response
 - 3.2.2. Liquid-like Response
- 4. Final Remarks

Food Rheology

283

- Mats Stading, SIK The Swedish Institute for Food and Biotechnology and Chalmers University of Technology, Gothenburg, Sweden
- 1. Introduction
- 2. Food rheology vs. food texture
- 3. Rheology of food dispersions
 - 3.1. Suspensions
 - 3.2. Emulsions
- 4. Food polymers and gels
 - 4.1. Food Polymers in Solution
 - 4.1.1. Starch
 - 4.2. Gels
- 5. Foams and dough rheology
- 5.1. Rheology in Bread Making
- 6. Processing and food rheology
 - 6.1. Fluid Transport
 - 6.2. Heat Transfer
 - 6.3. Mass Transfer
- 7. Experimental considerations
 - 7.1. Choice of Method
 - 7.2. Sample Handling
 - 7.3. Choice of Measuring Geometry
 - 7.3.1. Other Geometries
 - 7.4. Sample Loading
 - 7.5. Inhomogeneous Samples
 - 7.6. Artifacts
 - 7.6.1. Low-viscosity Fluids
 - 7.6.2. High-viscosity Fluids
- 8. Conclusions

Rheology of Surfactants: Wormlike Micelles and Lamellar Liquid Crystalline Phases

O. Manero, Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, A.P. 70-360, México, D.F., 04510

F. Bautista, Departamento de Física, Universidad de Guadalajara, Guadalajara, Jal., 44430, México J. E. Puig, Departamento de Ingeniería Química, Universidad de Guadalajara, Guadalajara, Jal., 44430, México

- 1. Introduction
- 2. Wormlike Micellar Systems
 - 2.1. Linear Viscoelasticity
 - 2.2. Non-linear Viscoelasticiy
 - 2.2.1. Shear banding Flow
 - 2.2.2. Transient flows
 - 2.2.3. Stability
 - 2.3. Shear banding and linear viscoelasticity
 - 2.4. Flow concentration coupling
 - 2.5. Shear thickening
- 3. Surfactant Lamellar Liquid Crystal Phases

4. Concluding Remarks

Biorheology

350

Bruno de Cindio, University of Calabria, Department of Engineering Modeling, Laboratory of Rheology and Food Engineering, Via P. Bucci, I 87030 Rende (CS), Italy Domenico Gabriele, University of Calabria, Department of Engineering Modeling, Laboratory of Rheology and Food Engineering, Via P. Bucci, I 87030 Rende (CS), Italy

1. Introduction

- 2. Blood as a Liquid-Like Material
- 3. Blood as a Solid-Like Material
- 4. Alternative Techniques for RBCs Elastic Behavior Evaluation
 - 4.1. Filtration
 - 4.2. Deformation in Microchannels
 - 4.3. Diffraction Techniques
 - 4.4. Alternative Approaches
 - 4.5. Final Comments
- 5. Effects of Pathologies on Blood Rheology
 - 5.1. Blood Disorders
 - 5.2. Kidney Pathologies
- 6. Other Types of Biological Fluids
- 7. Conclusion

Environmental Rheology – Rheology and the Triple Bottom Line

David V. Boger, FRS, Department of Chemical & Biomolecular Engineering The University of Melbourne, Australia

- 1. Introduction
- 2. Examples of Progress towards a More Sustainable Practice
 - 2.1. Alcoa Alumina in Western Australia
 - 2.2. The Minerals Industry as a Whole
- 3. Basic Rheological Properties
 - 3.1. Yield Stress Measurement
 - 3.1.1. The Vane Method
 - 3.1.2. The Slump Method
 - 3.2. Shear Stress-Shear Rate Measurements
 - 3.2.1. The Bucket Rheometer
 - 3.3. Rheological Flow Properties in Compression The Compressive Yield Stress and the Permeability
- 4. The Impact of Environmental Rheology
 - 4.1. In Design
 - 4.2. In Evaluation of the Influence of Surface Chemistry
- 5. Conclusion

Index

411

415

382

About EOLSS