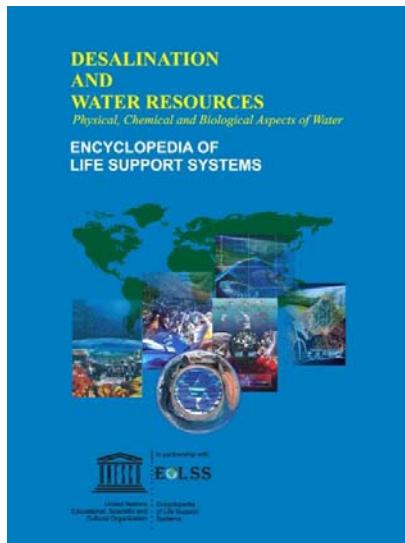


CONTENTS

DESALINATION AND WATER RESOURCES PHYSICAL, CHEMICAL AND BIOLOGICAL ASPECTS OF WATER



Physical, Chemical and Biological Aspects of Water - Volume 1

No. of Pages: 446

ISBN: 978-1-84826-424-3 (eBook)

ISBN: 978-1-84826-874-6 (Print Volume)

For more information of e-book and Print Volume(s) order, please [click here](#)

Or contact : eolssunesco@gmail.com

DESALINATION AND WATER RESOURCES (DESWARE)

International Editorial Board

Editor-in-Chief: Al-Gobaisi, D. M.K.

Members

Al Awadhi, A. Ali	Hammond, R. P.	Morris, R.
Al Radif, Adil	Hanbury, W. T.	Nada, N.
Al-Mutaz, I. S.	Harris, A.	Ohya, H.
Al-Sofi M.	Harrison, D.	Peluffo, P.
Andrianne, J.	Hassan, A. M.	Rao, G. P.
Awerbuch, L.	Hodgekiess, T.	Rautenbach, R.
Balaban, M.	Husain, A.	Reddy, K. V.
Beraud-Sudreau, D.	Ismat, K.	Saal, D.
Birkett, James D.	Karabelas, A.J.	Sadhukhan, H.K.
Blanco, J.	Kesou, A.	Sage, A.P.
Bodendieck, F.	Krause, H. P.	Sarkodie-Gyan,
Borsani , R.	Kubota, S.	Thompson
Bushnak, A. A.	Kumar, A.	Sommariva, C.
Capilla, A. V.	Kurdali, A.	Strathmann, H.
Catanzaro, E.	Laborie, J.	Temperley, T.
Damak, S.	Leitner, G. F.	Tleimat B.
Darwish, M. Ali	Lennox, F. H.	Todd, B.
Delyannis, E.u E.	Lior, N.	Tony F.
Dempsey J.	Ludwig, H.	Tusel, G.
El-Din, S.	Lukin, G.	Belessiotis, V.
El-Mahgary, Y.	Magara, Y.	Veza, J. M.
El-Nashar, A. M.	Makkawi B.	Vigneswaran, S.
El-Sayed, Y. M.	Malato, S.	Wade, N. M.
Finan, M. A.	Mandil , M.A.	Wang, S.
Furukawa, D.	Marquardt, W.	Wangnick, K.
Genthner, K.	McArthur,N.	Woldai A.
Germana, A.	Meller, F. H.	Watson, I. C.
Ghiazza, E.	Mewes, V.	Wessling, M.
Glade, H.	Michels, T.	Winters, H.
Goto, T.	Miyatake, O.	
Grabow, W. O.K.	Morin, O. J.	

CONTENTS

Electrochemical Processes 1
 Asghar Husain and Ali El Nashar, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

- 1. Introduction
 - 1.1. Electrochemical Cell
 - 1.2. Electrode Reactions
- 2. Faraday's Laws of Electrolysis
 - 2.1. First Law
 - 2.2. Second Law
- 3. Electrode Potential
 - 3.1. Equilibrium Potential
- 4. Types and Performance of Cells
 - 4.1. Voltaic Cells
 - 4.2. Electrolytic Cells
 - 4.3. Performance Characteristics
 - 4.4. Transport Number
 - 4.5. Activation Polarization
 - 4.6. Concentration Polarization
 - 4.7. Resistance Polarization
 - 4.8. Sum of the Polarization Effects
- 5. Applications
 - 5.1. Electrodialysis
 - 5.2. Electrochlorination
 - 5.3. Water Analysis
 - 5.3.1. Electrical Conductivity
 - 5.3.2. Dissolved Oxygen
 - 5.3.3. pH Measurement
 - 5.4. Corrosion of Metals

Biological Contamination of Water 18
 Asghar Husain, *International Center for Water and Energy Systems, Abu Dhabi, UAE*
 G. P. Reddy, *D.A.R Water Science and Technology, Hyderabad, India*

- 1. Range of Biological Organisms Present in Water
 - 1.1. Types of Organisms
 - 1.2. Types of Bacteria in Water
 - 1.2.1. Natural Water Bacteria
 - 1.2.2. Soil Bacteria
 - 1.2.3. Intestinal and Sewage Bacteria and Pathogens
 - 1.3. Influence of Water Conditions on Biological Activity
- 2. Metabolism of Bioorganisms
- 3. Biofouling
 - 3.1. Initiation
 - 3.2. Transport
 - 3.3. Attachment
 - 3.4. Removal
 - 3.5. Aging

Separation Thermodynamics 24
 Asghar Husain ,Ali El –Nashar and Adil Alradif, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

- 1. Relevant Thermodynamic Functions
- 2. Partial Molar Properties

- 2.1. Excess Properties
- 2.2. Activity Coefficient
- 3. Equilibrium Criteria
 - 3.1. Phase Equilibria
 - 3.2. Chemical Equilibrium
- 4. Aqueous Solutions of Electrolytes
 - 4.1. Work for Separation
- 5. Equilibria Relevant to Desalination
 - 5.1. Boiling Point Elevation (BPE)
 - 5.2. Vapor Pressure Lowering
 - 5.3. Freezing Point Depression
 - 5.4. Variation in Saturation Composition
 - 5.5. Osmotic Pressure
- 6. Thermodynamic Properties
 - 6.1. Osmotic Coefficient
 - 6.2. Enthalpies
 - 6.3. Heat Capacities
 - 6.4. Osmotic Pressure

Process Thermodynamics

50

Asghar Husain, Woldai A, Bushara M. and Ali El Nashar, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

- 1. Terminology
- 2. Variables and Properties
 - 2.1. Equilibrium
 - 2.2. Reversible Process
- 3. First Law of Thermodynamics
 - 3.1. Enthalpy
 - 3.2. Heat Capacity
 - 3.3. Open Systems
- 4. Equations of State
 - 4.1. The Ideal Gas
 - 4.2. Compressibility Factor
 - 4.3. Empirical Equations
- 5. Second Law of Thermodynamics
 - 5.1. Entropy Function
 - 5.2. The Fundamental Equations
 - 5.3. The Thermodynamic Network
- 6. The Equilibrium State
 - 6.1. Chemical Potential and Equilibrium Criteria
 - 6.2. Fugacity
 - 6.3. Activity Coefficient
- 7. Chemical Reaction Equilibrium
 - 7.1. Equilibrium Criteria and Constant

Separation Phenomena in Some Desalination Processes

89

Asghar Husain, Bushara, Ali El-Nashar and Aldil Alradif, *International Centre for Water and Energy Systems, Abu Dhabi, UAE*

- 1. Introduction
- 2. Solar Stills
- 3. Freeze and Hydrate Separation
- 4. Ion Exchange

Thermal Desalination Processes**99**

Asghar Husain, Adel Al Radif, Ali El-Nashar and Klaus Wagnick, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Introduction
 - 1.1. Single-effect Boiling
 - 1.2. Single-stage Flashing
 - 1.3. Dual-effect Boiling
2. Multiple Effect Boiling (MEB) Plants
 - 2.1. MEB Plant Analysis
3. Multistage Flash (MSF) Plants
 - 3.1. Temperature Profiles
 - 3.2. MSF Plant Analysis
 - 3.3. Energy Consumption
 - 3.4. Stage Temperature Loss (δTL)
 - 3.5. Non-equilibration Loss (δTE)
 - 3.6. BPE
 - 3.7. Demister Pressure Loss
 - 3.8. Condenser Pressure Loss
 - 3.9. Condenser Terminal Temperature Difference
 - 3.10. Fouling Factor
 - 3.11. Effect of Scaling
 - 3.12. Design Consideration
 - 3.13. Precise Analysis
4. Vapor Compression
 - 4.1. Mechanical Compression
 - 4.2. Thermal Compression

Membrane-Based Desalination Processes**137**

Asghar Husain, Ali El-Nashar and Adel Al Radif, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Introduction
 - 1.1. Membrane
 - 1.2. RO Membranes
 - 1.3. ED Membranes
2. Reverse Osmosis (RO) Theory
 - 2.1. Flux
 - 2.2. Concentration Polarization (CP)
 - 2.3. Salt Rejection
 - 2.4. Recovery
 - 2.5. Flux Determination
 - 2.6. Significant Product Concentration
 - 2.7. Membrane Transport Modeling
 - 2.7.1. Diffusion Equations
 - 2.7.2. Concentration Equations
 - 2.8. Capillary Flow Model
3. Electrodialysis (ED) Theory
 - 3.1. Basic Definitions
 - 3.1.1. Transport Number
 - 3.1.2. Permeability
 - 3.1.3. Equivalent Weight
 - 3.2. Desalting Rate
 - 3.3. Membrane Potential
 - 3.4. Energy Requirement
 - 3.5. Capacitative or Capacitive deionization
 - 3.6. Forward osmosis – uses osmosis itself for desalination

- 3.7. Historical Evolution of Reverse Osmosis (RO)
 - 3.7.1. Timelines –Membrane Desalination Technology
- 3.8. Future direction /innovations – seawater

Some Practical Aspects of Desalination Processes	168
Asghar Husain, Adil Al Radif, Ali El Nashar, Roberto Borsani and Bushara M, <i>International Center for Water and Energy Systems, Abu Dhabi, UAE</i>	

- 1. MEB Plants
 - 1.1. Forced Circulation Evaporator
 - 1.2. Rising Film Evaporator
 - 1.3. Falling Film Evaporator
 - 1.4. Horizontal Spray Film Evaporator
 - 1.5. Submerged Tube Evaporators
 - 1.6. Vapor Compression Evaporators
 - 1.7. Feed Paths in MEB Plants
 - 1.8. Optimum Number of Effects
- 2. MSF Plants
 - 2.1. Flashing Flow System
 - 2.2. Chemical Treatment
 - 2.3. Tube Configuration
 - 2.4. General Layout
 - 2.5. Main Operational Parameters
 - 2.6. Design Parameters
 - 2.7. Production Costs
 - 2.8. PR Optimization
 - 2.9. Comparison of MSF and MEB
- 3. RO Plants
 - 3.1. Plate and Frame Assembly
 - 3.2. Tubular System
 - 3.3. Spiral Wound System
 - 3.3.1. Mass Balances
 - 3.3.2. Pressure Drops
 - 3.4. Hollow Fiber Module
 - 3.4.1. Pressure Drops
 - 3.4.2. Brine Flow
 - 3.4.3. Product flow
 - 3.4.2. Membrane System
 - 3.4.3. Membrane Performance
 - 3.4.4. Membrane Fouling
- 4. ED Plants
 - 4.1. Spacers
 - 4.2. Membranes
 - 4.3. Electrodes
 - 4.4. Stack Layout
 - 4.5. Current Density
 - 4.6. Energy Requirement
 - 4.7. Polarity Reversal
 - 4.8. Organic Fouling
 - 4.9. Scaling
- 5. Limitations of the Membrane Processes

Properties of Natural Waters	210
Asghar Husain, Ali El Nashar, Adil Al radif and Bushara M, <i>International Center for Water and Energy Systems, Abu Dhabi, UAE</i>	
M. M. Ali, <i>IIC T Hyderabad, India</i>	

- 1. Some Basic Chemical Principles

- 2. Chemical Composition of Natural Waters
 - 2.1. Seawater
 - 2.2. Brackish Waters
 - 2.3. Solution Definitions
 - 2.3.1. pH Notation
- 3. Solubility in Water
 - 3.1. Solid Solubility in Water
 - 3.1.1. Scale Prevention Approaches
 - 3.2. Gas Solubility in Water
- 4. Thermodynamic and Transport Properties of Normal Seawater

Physical and Thermodynamic Properties of Water in the Liquid Phase 223

Asghar Husain, Ali El Nashar, Adil Al radif, Woldai A, *International Center for Water and Energy Systems, Abu Dhabi, UAE*
M.M. Ali, *IICT Hyderabad, India*

- 1. The Phases of Pure Water
- 2. Properties of Saturated Water and Steam
- 3. Properties of Compressed Liquid Water

General Characteristics of Water 240

Asghar Husain, Bushara, GPR, Samir Damak, *International Center for Water and Energy Systems, Abu Dhabi, UAE*
M. M. Ali, *IICT Hyderabad, India*

- 1. Pure Water
- 2. Natural Waters
 - 2.1. Rivers and Groundwaters
- 3. Seawater
 - 3.1. Salinity (S)
 - 3.2. Composition of Seawater
 - 3.3. Density
- 4. Energetic Aspects of Water
- 5. Biological Aspects of Water

An Overview of Fouling 251

T. Reg. Bott, *School of Chemical Engineering, University of Birmingham, Birmingham B15 2TT, UK*

- 1. Introduction
- 2. Categories of Fouling

Biofouling 262

T. Reg. Bott, *School of Chemical Engineering, The University of Birmingham, Birmingham B15 2TT, UK*

- 1. Introduction
- 2. Bacteria
- 3. Algae
- 4. Fungi
- 5. Mussels
- 6. Barnacles
- 7. Hydroids

Composite Fouling, Fundamentals and Mechanisms	270
R. Sheikholeslami, <i>School of Chemical Engineering and Industrial Chemistry, University of New South Wales, Sydney, Australia</i>	
A.P. Watkinson, <i>Department of Chemical and Bioresource Engineering, University of British Columbia, Vancouver, BC, Canada</i>	

1. Background
2. Crystallization Fouling
3. Particulate Fouling
4. Corrosion Fouling
5. Composite Fouling
6. Composite Crystallization and Particulate Fouling
7. Corrosion and Precipitation Fouling
8. Composite Corrosion and Particulate Deposition

Common Foulants in Desalination: Inorganic Salts	292
P. Koutsoukos, <i>University of Patras, School of Engineering, Department of Chemical Engineering, Patras, Greece</i>	

1. Description and Overview (relative occurrence)
2. Calcium Carbonate
3. Calcium Sulfate
4. Magnesium Hydroxide
5. Silica and Silicates
6. Phosphates
7. Others
 - 7.1 Manganese
 - 7.2 Calcium fluoride (CaF₂)
 - 7.3 Barium and Strontium sulfates

Crystallization Fouling	345
M. Jamialahmadi, <i>University of Petroleum Industry, Ahwaz, IRAN</i>	
H. Müller-Steinhagen, <i>School of Engineering in the Environment, University of Surrey, Guildford, Surrey, England</i>	

1. Introduction
2. Chemical Fundamentals
 - 2.1. CaCO₃ Solubility in Water
 - 2.2. Solubility of calcium carbonate for variable pH
 - 2.3. CaSO₄ Solubility in Water
 - 2.4. Scaling Indices
 - 2.4.1. Saturation Index
 - 2.4.2. Ryznar Stability Index
 - 2.4.3. Comparison of Indices for CaCO₃ Solutions
3. Literature Review on Scale Formation in Heat Exchangers
 - 3.1. Calcium sulfate
 - 3.2. Calcium carbonate
4. Effect of Operating Parameters on Scale Formation
 - 4.1. Effect of Salt Concentration
 - 4.2. Effect of Flow Velocity
 - 4.3. Effect of Heat Flux
 - 4.4. Effect of Surface and Bulk Temperature
 - 4.5. Effect of Ionic Strength
 - 4.6. Effect of Suspended Particles
 - 4.7. Effect of Surface Properties
5. Models for Scale Formation on Heat Transfer Surfaces

5.1. Crystallization Fouling During Forced Convective Heat Transfer	
5.1.1. Kern and Seaton Model (Kern and Seaton 1958)	
5.1.2. Reitzer Model (Reitzer 1964)	
5.1.3. McCabe-Robinson Model (McCabe and Robinson 1924)	
5.1.4. Taborek et al. (1972)	
5.1.5. Ritter Model (1983)	
5.1.6. Bohnet Model (1987)	
5.1.7. Hasson Model (1968, 1981)	
5.1.8. Watkinson and Martinez Model (1975, 1983)	
5.1.9. Chan and Ghassemi Model (1991)	
5.1.10. Najibi et al. Model (1977)	
5.2. Comparison of Measured and Predicted Results	
5.3. Crystallization Fouling under Subcooled Flow Boiling Conditions	
6. Scale Formation in Shell and Tube Heat Exchangers	
7. Scale Formation in Plate and Frame Heat Exchangers	
8. Extended Surfaces	

Biological Foulants	400
T.R. Bott, <i>School of Chemical Engineering, The University of Birmingham, Birmingham B15 2TT, UK</i>	

1. Biofouling	
---------------	--

Change of Distiller Performance with Fouling	403
Frank Bodendieck and Klaus Gentner, <i>University of Bremen, Germany</i>	

1. Introduction	
2. Relationship Between Fouling and Steam Consumption	
3. Performance of the Evaporator Under Different Tube Fouling Conditions	
3.1. Design Specifications and Heat Balances of an MSF Plant	
4. The Effect of Various Fouling Conditions on Various Plant Sections	
4.1. Performance Ratio	
4.2. Overall Heat Transfer Coefficient and Heat Flux per Stage	
4.3. The Effect of Various Fouling Conditions on Temperature Distribution in the MSF Plant	
4.4. The Effect of Various Fouling Conditions on Flow Changes of the MSF Plant	
4.5. The Effect of Various Fouling Conditions on the Distillate Purity of an MSF Plant	

Index	421
--------------	------------

About DESWARE	427
----------------------	------------