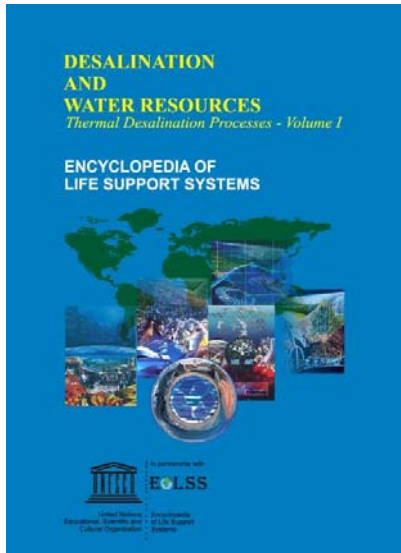


CONTENTS

DESALINATION AND WATER RESOURCES THERMAL DESALINATION PROCESSES



Thermal Desalination Processes - Volume 1

No. of Pages: 480

ISBN: 978-1-84826-425-0 (eBook)

ISBN: 978-1-84826-875-3 (Print Volume)

Thermal Desalination Processes - Volume 2

No. of Pages: 476

ISBN: 978-1-84826-426-7 (eBook)

ISBN: 978-1-84826-876-0 (Print Volume)

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

Or [contact : eolessunesco@gmail.com](mailto:eolessunesco@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.
Andriane, 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

VOLUME I

MSF Engineering 1

M.A. Darwish, *Department of Mechanical and Industrial Engineering, Kuwait University, Kuwait*

1. Introduction
2. Once-through MSF System
 - 2.1. Single-stage Flash System
 - 2.2. Two-stage Flash System
 - 2.3. Multistage (n-stage) systems
3. Recirculation MSF System
 - 3.1. Recirculation arrangements
 - 3.2. Thermal Analysis of the Recirculation MSF System
 - 3.3. The Recirculation to Distillate Ratio R/D
 - 3.4. Terminal Temperature Difference
4. Performance Ratio
5. Heat Transfer Area of the Stages Condenser
6. Flow Sheet Development
7. Maintenance Design Features
 - 7.1. Operating Temperature
 - 7.2. Flashing Brine Flow and Vapor Release Velocity
 - 7.2.1. Stage Width
 - 7.2.2. Stage Length
 - 7.2.3. Vapor Velocity and Stage Area
 - 7.3. Gain Ratio or Performance ratio
 - 7.4. Rated Capacity
 - 7.5. Number of Stages n
 - 7.6. Temperature Profile
 - 7.6.1. Temperature Losses $\delta_{tr} \ell$
 - 7.6.2. The Stage Temperature Approach δ_{tc}
 - 7.7. Stage Efficiency η_i
 - 7.8. Deaeration
 - 7.9. Dearators
 - 7.10. Venting System
 - 7.11. Brine Level
 - 7.12. Concentration Ratio
 - 7.13. Plant Control and Instrumentation
 - 7.13.1. Top Brine Temperature
 - 7.13.2. Cooling Seawater Temperatures
 - 7.13.3. Last Stage Brine Level
 - 7.13.4. pH Control
8. Component Design and Material
 - 8.1. Evaporator Stage
 - 8.2. Interstage Control Devices
 - 8.2.1. Sluice Gates
 - 8.2.2. Box Type Orifice
 - 8.2.3. Interstage Pressure Drop
 - 8.3. Condensers Design
 - 8.3.1. Heat Transfer Relations
 - 8.3.2. Condensing Heat Transfer Coefficient (hC)
 - 8.3.3. Brine Side-forced Convection Coefficient (h)
 - 8.3.4. Thermal Resistance of Walls
 - 8.3.5. The Fouling Resistance (rf)
 - 8.3.6. Effect of Non-condensable Gases

- 8.3.7. Condenser Materials
- 8.3.8. Waterboxes
- 8.4. Demisters
- 8.5. Product Water Troughs
- 8.6. Pumps
 - 8.6.1. A Typical Kuwaiti Plant
- 9. Rational Basis for Energy Comparison
 - 9.1. Specific Mechanical Work Consumption
- 10. Cost Estimation
 - 10.1. Energy Requirements for an MSF System
 - 10.2. Direct Boiler Driven MSF System
- 11. MSF Steam Supply to an MSF Desalting Plant from a Co-generation Turbine
 - 11.1. The Rating of Dual-purpose Power/Desalting Plants
 - 11.1.1. Rating of Single-purpose Power Plants
- 12. Reference Dual-purpose Power/Desalination Plant
 - 12.1. Energy Charged to Desalted Water by Different Allocation
 - 12.1.1. Method A: All Benefits of Dual-purpose Plants are Given to Power Production
 - 12.1.2. Method B: All Benefits are Given to the Desalting Process
 - 12.1.3. Method C: Available Energy Method
 - 12.1.4. Method D: Energy Allocated by Work Loss due to Extraction of Steam to Desalter
- 13. Conclusion

Science and Technology of Chemical Dosing for Desalination: History, Developments and Future Trends **95**

E. Bryan and R.E. Talbot, *Albright and Wilson UK Ltd.*

- 1. Scope
- 2. History
- 3. Overview of Dosing Systems
- 4. Acid Dosing Systems
- 5. Threshold Scale Control Additives
- 6. Sulphite Dosing Systems
- 7. Antifoams
- 8. Chlorine
- 9. Ferrous Sulphate
- 10. Safety
- 11. Future trends

Control Scheme of Multistage Flash Plants **112**

T. Knohl, A. Gambier and H. Unbehauen, *Ruhr-Universität Bochum, Germany*

- 1. Introduction
- 2. Principle of MSF Desalination
- 3. Defining the System for Control
 - 3.1. The Degrees of Freedom
 - 3.2. Selection of Variables
 - 3.2.1. Variables Related to Plant Protection
 - 3.2.2. Variables Related to the Efficiency of the Plant
 - 3.2.3. Variables Related to the Product Quality
 - 3.2.4. Variables for Environment Protection
 - 3.2.5. Summary of the Variables
- 4. An Overview of Control Strategies for MSF Plants
 - 4.1. Classical Control
 - 4.2. Advanced Control Design
 - 4.2.1. Adaptive Control
 - 4.2.2. Fuzzy Control

- 4.2.3. Neurocontrol
- 4.2.4. Knowledge-based Systems for Control

On-Line Optimization of MSF Desalination Plants

136

A. Mhamdi, W. Geffers, F. Flehmig and W. Marquardt, *Lehrstuhl für Prozeßtechnik RWTH Aachen University of Technology, Germany*

1. Introduction
2. Steady-state MSF Model
3. Steady-state Detection
 - 3.1. Application to MSF Measurements
4. Data Reconciliation and Gross Error Detection
 - 4.1. Data Reconciliation
 - 4.2. Gross Error Detection
 - 4.2.1. Statistical Tests
 - 4.2.2. Serial Elimination Method
 - 4.3. Application to MSF Plants
 - 4.3.1. Data Reconciliation without Gross Errors
 - 4.3.2. Detection of Gross Errors
5. Optimization of Operating Conditions
 - 5.1. Problem Formulation and Solution Methods
 - 5.2. Application to MSF Plants
 - 5.2.1. Objective Function and Decision Variables
 - 5.2.2. Process Constraints
 - 5.3. Simulation Case Study
 - 5.3.1. Maximizing Distillate Production
 - 5.3.2. Maximizing Performance Ratio
6. Implementation of Real-time Optimization
 - 6.1. Implementation of the On-line Optimization Structure
 - 6.2. Scheduling of On-line Optimization Modules
 - 6.3. Case Study: Maximizing Production Rate
7. Conclusion

The Need for Multivariable Control in MSF Desalination Plants

163

Joachim Blum and Wolfgang Marquardt, *Lehrstuhl für Prozeßtechnik, RWTH Aachen University of Technology, Germany*

1. Introduction
2. Controllability Analysis
 - 2.1. The MSF Feedback Control Problem
 - 2.2. Controllability Measures
 - 2.2.1. Basic Procedure
 - 2.2.1.1. Inherent Performance Limitations
 - 2.2.1.2. Constraints on Manipulated Variables
 - 2.2.2. Results
 - 2.3. Control Structure Selection
 - 2.3.1. Results
3. Robust Control
 - 3.1. Theoretical Foundations
 - 3.2. Uncertainty Description
 - 3.3. Model Reduction
 - 3.4. Controller Design and Evaluation
4. Conclusions

Process Optimization - Cost Criteria**188**O.J. Morin, *Black and Veatch, Florida, USA*

1. Introduction
2. Process Design and Cost Criteria
 - 2.1. General
 - 2.2. Process Design Criteria
 - 2.2.1. Plant Capacity
 - 2.2.2. Number of Units
 - 2.2.3. Feedwater Quality
 - 2.2.4. Pre-treatment Requirements
 - 2.2.5. Finished Water Quality
 - 2.2.6. Post-treatment Requirements
 - 2.2.7. Materials of Construction
 - 2.3. Cost Criteria
 - 2.3.1. Direct Capital Cost Basis
 - 2.3.2. Indirect Capital Cost Basis
 - 2.3.3. Operating Cost Basis
3. Energy Supply Alternatives
 - 3.1. General
 - 3.2. Energy Sources
 - 3.3. Process Arrangement
 - 3.3.1. Single Purpose
 - 3.3.2. Dual Purpose
 - 3.4. Process Energy Use
 - 3.4.1. Single Purpose
 - 3.4.2. Dual Purpose
 - 3.5. Comparison
4. Process Optimization
 - 4.1. General

Steady-State Model**210**Asghar Husain, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Literature Review
2. Stage Model
3. Interstage Model
4. Brine Heater Model
5. Splitter Equations
6. Auxiliary Equations
7. Model Solution

Steady-State Simulation**246**Asghar Husain, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Process Constraints
 - 1.1. Top Brine Temperature
 - 1.2. Brine Recycle Rate
 - 1.3. Make-up Flow Rate
 - 1.4. Seawater Flow Rate and Temperature
2. Performance Simulation
 - 2.1. Simulation with SPEEDUP
3. Discussion of Results

Process Optimization

264

Asghar Husain, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Setpoint Variables
2. Technical Criteria for Optimization
 - 2.1. Sequential Iterative Logic
 - 2.2. Partial Load Operation
 - 2.2.1. Stable Operation
 - 2.2.2. Interstage Transfer
 - 2.2.3. Condenser Performance
 - 2.2.4. Partial Load Simulation

Dynamic Model

278

Asghar Husain and K.V. Reddy, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Literature Review
 - 1.1. Devices and Connections
 - 1.2. DAE System and its Index
 - 1.3. Dynamic Model Solution
 - 1.4. MSF Modeling
 - 1.5. Holdup and Interstage Orifice Flow
2. Brine Heater Model
 - 2.1. Model Version 1
 - 2.2. Model Version 2
 - 2.3. Auxiliary Equipment
 - 2.3.1. Desuperheater Model
3. Stage Model
 - 3.1. Distillate Product
 - 3.2. Vapor Space
 - 3.3. Cooling Brine
4. Interstage Flow
 - 4.1. Stages with Kick-plates
 - 4.1.1. Level at the Vena Contracta
 - 4.1.2. Level Upstream of the Orifice
 - 4.2. Brine Holdup
 - 4.2.1. Hydraulic Jump Profile
 - 4.2.2. Region of Gradually Varied Flow
 - 4.3. Holdup Calculation in Dynamic Simulation
 - 4.3.1. Steady-state Simulation
 - 4.4. Non-condensables and Vapor Flow
 - 4.4.1. Dissociation Constants
 - 4.5. Carbon Dioxide Release
 - 4.5.1. Mechanism 1
 - 4.5.2. Mechanism 2
 - 4.5.3. Henry's Law
 - 4.5.4. Carbon Dioxide Release Models
 - 4.5.5. Watson Model
 - 4.5.6. Carbon Balance
 - 4.5.7. Model with Mass Transfer
 - 4.5.8. Stagewise Release of Carbon Dioxide
 - 4.5.9. Role of the TBT
 - 4.5.10. Parametric model
 - 4.6. Modeling Venting System
 - 4.6.1. Ejector Model
 - 4.6.2. Vent Condenser Model
 - 4.6.2.1. Shell side
 - 4.6.2.2. Tube side

5. Control Loops
 - 5.1. Valve Model
 - 5.2. Controller Model
 - 5.3. Control Schemes
 - 5.3.1. Cascade Control
 - 5.3.2. Compensation Control
 - 5.3.3. Superheated Steam Control
 - 5.4. Brine Heater Control Simulation
6. Pipeline Networks
 - 6.1. Pump Characteristics
 - 6.2. Valves
 - 6.3. Pipes and Pipe Fittings
7. Dynamic Simulation
8. Conclusion

Dynamic Modelling and Simulation: Modelling Concepts and Model Overview **352**
 F. Flehmig, R.V. Watzdorf and W. Marquardt, *Lehrstuhl für Prozeßtechnik RWTH Aachen University of Technology, Germany*

1. Introduction
2. Modelling Concepts
3. MSF Plant Model Overview
 - 3.1. Brine Heater
 - 3.1.1. Brine in Tubes
 - 3.1.2. Vapor Phase
 - 3.1.3. Inlet and Outlet Waterboxes
 - 3.1.4. Condensate Channel
 - 3.1.5. Desuperheater
 - 3.1.6. Valve
 - 3.2. Evaporator
 - 3.2.1. Flashed Brine
 - 3.2.2. Vapor Phase
 - 3.2.3. Brine in Tubes
 - 3.2.4. Deaerator
4. Conclusion

Dynamic Modeling and Simulation: Brine Flow Hydraulics **372**
 F. Flehmig, R.V. Watzdorf, W. Marquardt and K.V. Reddy, *Lehrstuhl für Prozeßtechnik RWTH Aachen University of Technology, Germany*

1. Introduction
2. Experimental Data
3. Mathematical Description
 - 3.1. Submerged Flow
 - 3.1.1. Contraction Coefficient Approach
 - 3.1.2. Pressure Drop Approach
 - 3.1.3. Discussion
 - 3.2. Blow Through
4. Illustrative Examples
5. Conclusion

Dynamic Modelling and Simulation: Non-Equilibrium Effects and Heat Transfer **386**
 F. Flehmig, R.V. Watzdorf and W. Marquardt, *Lehrstuhl für Prozeßtechnik RWTH Aachen University of Technology, Germany*

1. Introduction

2. Non-equilibrium Effects
 - 2.1. Non-equilibrium Temperature Loss
 - 2.2. Empirical Correlations for the Non-equilibrium Temperature Loss
 - 2.3. Non-equilibrium in Industrial-Scale Experiments
3. Heat Transfer
 - 3.1. Clean Heat Transfer Coefficients and Fouling Factors
 - 3.2. Experimental Results
4. Conclusion

Dynamic Modeling and Simulation: Model Validation and Simulation Studies

399

F. Flehmig, R. Von Watzdorf and W. Marquardt, *Lehrstuhl für Prozesstechnik RWTH Aachen University of Technology, Germany*

1. Introduction
2. Model Description
 - 2.1. Balance Equation
 - 2.2. Brine Flow
 - 2.3. Non-equilibrium
 - 2.4. Heat Transfer
3. Dynamic Plant Experiments
4. Model Validation
 - 4.1. Literature Review
 - 4.2. Weak Plant Excitation
 - 4.3. Strong Plant Excitation
 - 4.4. Switch from Maximum to Minimum Load
5. Conclusion

Simulator

417

Ashgar Husain, *International Center for Water and Energy Systems, Abu Dhabi, UAE*

1. Training Simulator
 - 1.1. Simulator Structure
 - 1.1.1. Dynamic Model
 - 1.1.2. Control Systems
 - 1.1.3. Man-Machine Interface
 - 1.2. Classification and Realization
 - 1.3. Training Strategy
2. Simulator for an MSF Plant
 - 2.1. Start-up Model and Simulation
 - 2.1.1. Start-up Procedure
 - 2.1.2. Start-up Modeling
 - 2.1.2.1. Flash Stages
 - 2.1.3. Pipeline Networks
 - 2.1.3.1. Start-up Simulation
 - 2.1.4. Results and Discussion
 - 2.1.4.1. Filling of the Bottom Deck
 - 2.1.4.2. Recycle Flow
 - 2.1.4.3. Evacuation
 - 2.1.4.4. Preheating
 - 2.1.4.5. Control during Start-up
 - 2.1.4.6. Summing Up
 - 2.2. Integrated Simulator
 - 2.2.1. Module Tuning and Testing
 - 2.2.2. Instructor Functions
 - 2.2.3. Field Operator Functions
 - 2.2.4. Malfunctions

- 2.3. Constrained Model Predictive Control
 - 2.3.1. Constrained Mode Predictive Control Model
 - 2.3.2. Step Response Model
 - 2.3.2.1. Optimization in CMPC
 - 2.3.2.2. MSF Process Optimization
- 3. Conclusions

Index **449**

About DESWARE **453**

VOLUME II

Cost Aspects – MSF **1**
O.J. Morin, Black and Veatch, Florida, USA

- 1. Introduction
- 2. Purpose
- 3. Reference Design
- 4. Site Specific Factors
 - 4.1. Plant Capacity
 - 4.1.1. Single Train
 - 4.1.2. Multiple Trains
 - 4.2. Operating Cost
 - 4.3. Performance Ratio
 - 4.4. Summary of Scaling Factors
 - 4.5. Blending
 - 4.6. Components Included in the Cost
 - 4.7. Concentrate Disposal
 - 4.8. Intake Types
 - 4.8.1. Types
 - 4.8.2. Intake Cost Basis
 - 4.8.3. Intake Costs
 - 4.9. Pre and Post Treatment
 - 4.9.1. Pre-Treatment
 - 4.9.2. Post-treatment
- 5. Cost Development Factors
 - 5.1. Indirect Costs
 - 5.1.1. Introduction
 - 5.1.2. Freight and Insurance
 - 5.1.3. Owner's Costs
 - 5.1.4. Construction Overhead and Profit
 - 5.1.5. Engineering
 - 5.1.6. Contingency
 - 5.2. Cost Development and Presentation
 - 5.2.1. Introduction
 - 5.2.2. Method A - Direct and Indirect Costs
 - 5.2.3. Method B - Indirect Costs with Working Capital and Interest During Construction
 - 5.2.4. Method C - Indirect Costs with Bonding Costs
 - 5.2.5. Method D - Cost of Water over the Service Life
 - 5.2.6. Cost Summary
- 6. Cost Calculation Methods
 - 6.1. First Year Costs
 - 6.1.1. Labor
 - 6.1.2. Energy
 - 6.1.3. Chemicals

- 6.1.4. Replacement Parts, Maintenance Materials and Insurance:
- 6.1.5. Fixed Charges:
- 6.2. Levelized Cost of Water

Introduction and Definitions

31

J.D. Birkett, *West Neck Strategies, USA*

- 1. Basic Principles
 - 1.1. The Evaporating Zone
 - 1.2. The Condensing Zone
 - 1.3. Vapor Transport
 - 1.4. Energy Input
 - 1.5. Energy Efficiency
 - 1.6. Multiple Effect
 - 1.7. Vapor Compression
 - 1.8. Summary
- 2. Developments since 1950

Multi-Effect Distillation (MED)

37

Raphael Semiat, *Rabin Desalination Laboratory, Grand Water Research Institute, Wolfson Faculty of Chemical Engineering, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel*

- 1. Introduction
- 2. Desalination Techniques
 - 2.1. Membrane Processes
 - 2.1.1. Reverse Osmosis (RO)
 - 2.1.2. Nano-Filtration
 - 2.1.3. Ultra-Filtration and Micro-Filtration
 - 2.1.4. Electro-dialysis
 - 2.2. Evaporative Techniques
 - 2.2.1. Multi-Stage Flash
 - 2.2.2. Multi-Effect Distillation
 - 2.2.3. Vapor Compression
- 3. MED Design Issues
 - 3.1. Heat Transfer in MED
 - 3.2. Orientation and Scaling
- 4. Design Equations
 - 4.1. Single-Stage Evaporator
 - 4.2. Multi-Stage Evaporator
 - 4.3. Energy Needs for Vapor Compression
 - 4.3.1. VC with Mechanical Compressor
 - 4.3.2. Energy Demand in Thermal Vapor Compression
- 5. Operational Issues
 - 4.3. Energy Needs for Vapor Compression
 - 4.3.1. VC with Mechanical Compressor
 - 4.3.2. Energy Demand in Thermal Vapor Compression
 - 5.1. Pre-treatment
 - 5.2. Product Quality
 - 5.3. Product Post-Treatment
 - 5.4. Corrosion Protection
 - 5.5. Scale Prevention
 - 5.6. Non-Condensable Gases
- 6. Environmental, Energy Issues and Future Trends
 - 6.1. Environmental Aspects
 - 6.2. Energy Consumption
 - 6.3. Product Cost

7. Future Trends
8. Conclusions

Fundamentals of Multiple Effect Evaporation

78

M.A. Darwish, *MIED, Kuwait University, Kuwait*

1. Introduction
2. Single-effect Submerged Tube System
 - 2.1. Performance Ratio of the Single-effect Distillation System
 - 2.2. Heat Transfer Area of a Single-effect desalting (SED) System
 - 2.2.1. Evaporator Heat Transfer Area: A_e
 - 2.2.2. Condenser Heat Transfer Surface Area: A_c
 - 2.2.3. The Optimum Total Area of the Condenser and Evaporator: A_t
3. Multieffect Boiling of a Submerged Tube Desalination System
 - 3.1. Forward Feed Arrangement
 - 3.2. Backward Feed Arrangement
 - 3.3. Parallel Feed Arrangement
 - 3.3.1. Forward Feed Multieffect Distillation
 - 3.3.1.1. Example 1
 - 3.3.1.2. Example 2
 - 3.3.1.3. Solution
 - 3.3.2. Backward Feed Multieffect System
4. Modern Multieffect Boiling Desalination with Regenerative Heating System
 - 4.1. Multieffect Falling Film Evaporators
 - 4.2. Thermal Analysis
 - 4.2.1. The Gain Ratio
 - 4.2.2. Heat Transfer Area
 - 4.2.3. Number of Effects
 - 4.2.3.1. Example 3.3
 - 4.2.3.2. Solution
 - 4.2.3.3. Optimum Number of Effects
 - 4.2.3.4. Effect Arrangement and Containments
 - 4.2.3.5. Conclusions
5. Mechanically Driven Compressor
 - 5.1. Thermodynamic Analysis
 - 5.1.1. Work Done
 - 5.1.2. Heat Transfer Surface Areas
 - 5.1.3. Energy Consumption
 - 5.2. Multieffect Vapor Compression System
 - 5.2.1. Vapor Compression Multieffect Analysis
 - 5.2.1.1. Example
 - 5.2.1.2. Solution
 - 5.2.1.3. Example
 - 5.2.1.4. Solution
 - 5.2.1.5. Example
 - 5.2.1.6. Solution
6. Thermally Driven Compressor
 - 6.1. Example
 - 6.2. Solution
 - 6.3. Multieffect Thermovapor Compression System
 - 6.3.1. Example

Vertical Tube Evaporators

154

R.P. Hammond, *Consulting Engineer, Laguna Hills, California, USA*

H.H. Sephton, *Sephton Water Technology, USA*

1. Introduction

- 1.1. Advantages of the Vertical Tube Process
2. Feed Heating and Feed Control
 - 2.1. Forward and Backward Feed
 - 2.2. Mixed Feed
 - 2.3. Feed Control
 - 2.4. Feed Control during Start-up and Shut-down
 - 2.5. Condenser Control
3. Upflow versus Downflow
4. Fluted Tubes for Vertical Evaporators
 - 4.1. Description of Flutes
 - 4.2. Mechanism of Enhanced Condensing Performance
 - 4.3. Evaporative Enhancement
 - 4.3.1. Wave Flow
 - 4.3.2. Foaming Flow
 - 4.4. The Fin Effect
 - 4.5. Combined Enhancement
 - 4.6. Other Factors Affecting Heat Transfer Performance
 - 4.6.1. Flute Profile
 - 4.6.2. Thermal Conductivity and Tube Wall Thickness
 - 4.6.3. Tube Length
 - 4.6.4. Temperature Difference
 - 4.6.5. Feed Rate
 - 4.6.6. Foaming Flow
 - 4.6.7. Effect of Fouling
5. Scale Control and the Use of Surfactants
6. Steam Path Design of the Vertical Tube Bundle
7. Plant Layout and Arrangement
8. Process Control and Instrumentation
9. Operating Experience with Vertical Tube Evaporators
10. Case Studies
 - 10.1. Barge-mounted Vertical Tube Evaporator
 - 10.2. The Metropolitan Water District Tower Design

Horizontal Tube Multiple Effect - Stacked Design

179

R. Rautenbach and J. Widua, *Institut für Verfahrenstechnik der RWTH, Germany*

1. Introduction
2. Hydraulic Design
 - 2.1. Influence of Evaporator Design (Tube Bundle Geometry) on Plant Performance
 - 2.2. Brine Distribution in MES Design
 - 2.2.1. Brine Distribution by Sieve Trays
 - 2.2.2. Brine Distribution by Nozzles
 - 2.3. Minimum Wetting Rates
 - 2.3.1. Siphon Design
3. Heat Transfer
 - 3.1. Heat Transfer Coefficient - Influence of Noncondensable Gases
 - 3.2. Seeding in the HT Evaporator
4. Case Studies
 - 4.1. The Abu Dhabi Solar Heated Pilot Plant
 - 4.2. The Al Ain Solar Heated Pilot Plant
 - 4.3. Large-scale, Stacked Desalination Unit of Orange County Water Authority (USA)

Mechanical Vapor Compression Distillation

208

B. Tleimat, *Water Re-use Technology, Alamo, California, USA*

1. Process Description

2. Process Analysis
3. Effects of Salinity and Temperature on Energy Consumption
4. System Heat Balance
5. Heat Transfer Surface Requirement
6. Effects of Evaporator Temperature on Heat Transfer Area
7. Effects of Evaporator Type on Energy
8. Multieffect Vapor Compression Distillation
9. Comparison of Single-effect and Multieffect Vapor Compression Distillation Systems
10. Forced Circulation Vapor Compression
11. Compressors
12. Comparison of Lobe-type and Centrifugal Compressors

Modeling, Dynamics and Control of Horizontal Tube Falling Film Multieffect Desalination Plants

J. Hackenberg, A. Helbig and W. Marquardt, *Lehrstuhl für Prozesstechnik RWTH Aachen University of Technology, Germany* **242**

1. Introduction
2. Dynamic Modeling of ME Distillers
 - 2.1. Model Overview
 - 2.2. Effect Model
 - 2.2.1. Model Structure
 - 2.2.2. Heat Transfer Coefficients
 - 2.2.2.1. Film Evaporation on the Outside Surface of a Horizontal Tube
 - 2.2.2.2. Condensing Vapor inside a Horizontal Tube
 - 2.2.3. Condensate Flow from the Tube Bundle Inside
 - 2.3. Carbon Dioxide Release
 - 2.4. Steam Jet Ejector Modeling
 - 2.4.1. Equations for Steam Jet Ejector Model
3. Dynamics and Controllability Analysis
 - 3.1. Dynamic Simulation Results
 - 3.2. Controllability Analysis
 - 3.2.1. Inherent Performance Limitations
 - 3.2.2. Bandwidth Requirements and Practical Limitations
 - 3.2.3. Performance Limitations by Manipulated Variables Constraints
 - 3.2.4. Controllability Summary
4. Decentralized Control
 - 4.1. Control Structure Selection
 - 4.2. Controller Design and Performance Evaluation
 - 4.3. Decentralized Control Summary
5. Model Predictive Control
 - 5.1. MPC Implementation
 - 5.2. Base Control Studies
 - 5.3. Production Control Studies
6. Conclusion

Freezing Desalination Process

275

Z. Lu and L. Xu, *Department of Environmental Engineering, East China University of Science and Technology, China*

1. Introduction
2. Desalination Freezing Process
 - 2.1. Basic Components in the Freezing Processes
 - 2.2. Indirect Freezing Process
 - 2.3. Direct Freezing Processes
 - 2.3.1. Secondary Refrigerant Freezing Process
 - 2.3.2. Vacuum-freezing Process

- 2.3.3. Vacuum-freezing Vapor Compression (VFVC) Process
- 2.3.4. Vacuum-freezing Vapor Absorption Process
- 2.3.5. Vacuum-Freezing Ejector Absorption (VFEA) Process
- 2.3.6. Vacuum-freezing High Pressure Ice Melting (VFPIM) Process
- 2.3.7. Vacuum-freezing Multiple Phase Transformation Process
- 3. Comments on Freezing Processes
- 4. Future Prospects

Design of Multiple Effect Forced-Circulation Evaporators and Crystallization Systems **291**

U. Hansen and W. Hinsen, *Balcke-Dürr, Ratingen, Germany*

A. Pavlik, *Balcke-Dürr, Swenson, France*

- 1. Features and Applications of Forced-circulation Evaporators
- 2. Multiple-effect Forced-circulation Evaporator
- 3. Thermodynamic Design
- 4. Hydraulic Design
- 5. Brine Distribution
- 6. Concentration Process for Vinasses from Distilleries and Yeast Production
 - 6.1. Process Description
 - 6.1.1. Multiple-effect Evaporators
 - 6.1.2. Mechanical Vapor Recompression
 - 6.2. Description of Equipment
 - 6.2.1. Evaporators
 - 6.2.2. Elutriation of the Crystals
 - 6.2.3. Separation of Crystals
 - 6.2.4. Clarification of Concentrated Vinasses
 - 6.3. Utility Consumption
 - 6.4. Product Quality
 - 6.4.1. Concentrated Vinasses
 - 6.4.2. Potassium Sulfate Crystals
 - 6.5. Operating Cycles
 - 6.6. Operating Data of Plants Already Built
 - 6.7. Conclusion

Rotary Evaporators **305**

B. Tleimat, *Water Re-use Technology, California, USA*

- 1. Historical Background
- 2. Analysis
 - 2.1. Rotating Disk Evaporators Without Wipers
 - 2.2. Rotating Disk Evaporators with Wipers
- 3. Specific Energy for Rotors
- 4. Performance of Rotating Evaporators

Small Desalination Plants (SDPS) **346**

Himangshu K. Sadhukhan and Pradip K. Tewari, *Bhabha Atomic Research Centre, Mumbai 400085, India*

- 1. Introduction
- 2. Single-effect and Multieffect Distillation
- 3. Vapor Compression
- 4. Multistage Flash
- 5. Electrodialysis
- 6. Reverse Osmosis
- 7. Solar Distillation and Solar Energy-driven Plants

8. Freezing
9. Ion Exchange
10. Solvent Process
11. Membrane Distillation
12. Conclusions

Suggestions for Future MSF-Plant Design

357

R. Rautenbach and S. Schafer, *Rheinisch-Westfälische Technische Hochschule Aachen, Institut Für Verfahrenstechnik, Turmstraße 46, D-52056 Aachen, Germany*

1. Introduction
2. Key data of Recommended Future MSF Plants
3. Plant Design Aspects
 - 3.1. Comparison of Brine Recycle and Once Through Mode
 - 3.2. Comparison of Cross Tube and Long Tube Design
 - 3.3. Single Tier instead of Double Tier Design
 - 3.4. Elevation of the Distiller about 11 m above Ground Level.
 - 3.5. Increased Specific Weir Loads and Optimized Interstage Orifices
4. Operation Aspects
 - 4.1. Increased Top Brine Temperature
 - 4.2. Partial Load Operation
 - 4.3. Seawater Treatment and Scale Prevention Methods
5. Auxiliaries
 - 5.1. Redundancy of Equipment
 - 5.2. Speed Control Pumps
 - 5.3. Venting System
6. Materials
7. Startup, Instrumentation

The Economics and Performance of Desalination Plants

373

Ali M El-Nashar, *Consultant, International Centre for Water and Energy Systems, Abu Dhabi, UAE*

1. Introduction
2. Description of the Seawater Desalination Processes
 - 2.1. Multi Stage Flash (MSF) Distillation Process
 - 2.2. Multiple Effect Distillation (MED) Process
 - 2.3. Multiple Effect Distillation -Thermal Vapor Compression (MED-TVC) Process
 - 2.4. Seawater Reverse Osmosis (SWRO) Process
 - 2.4.1. RO Configurations
3. Performance Model Description and Thermo-economic optimization model using the exergy principle
 - 3.1. Multi Stage Flash (MSF) Distillation Process
 - 3.2. Multiple Effect Distillation (MED) Process
 - 3.3. Multiple Effect Distillation- Thermal Vapor Compression (MED-TVC) Process
 - 3.4. Seawater Reverse Osmosis (SWRO) Process Model
4. Comparison of the energy consumption of desalination processes
5. Economics of Desalination Processes
6. Available desalination economic computer models
 - 6.1. WTCost© Model
 - 6.2. DEEP Model
 - 6.3. WRA RO Cost Model
 - 6.4. La Sapienza “CAMEL Pro” Model
 - 6.5. The MEDRC Model
7. Operational and economic parameters used in the sample calculations
8. Sample desalination plant costing Calculations
 - 8.1. Multistage Flash (MSF) Distillation Process
 - 8.2. Multiple Effect Distillation (MED) Process

- 8.3. Seawater RO Process
- 9. Process cost comparison
- 10. Seawater Reverse Osmosis (SWRO) process costs
- 11. Desalination project financing strategies

Index	443
About DESWARE	449