الجمعية المغربية للأغشية وتحلية المياه
SMMD
Société Marocaine des Membranes et de Dessalement

MEDRC

مركز الدراسات والأبحاث للفوسفاط المعدني
CERPHOS

4-day intensive course on

Brackish and Seawater Desalination using NF and RO Membranes: *Transport Theory, Modeling, and Process Simulation*

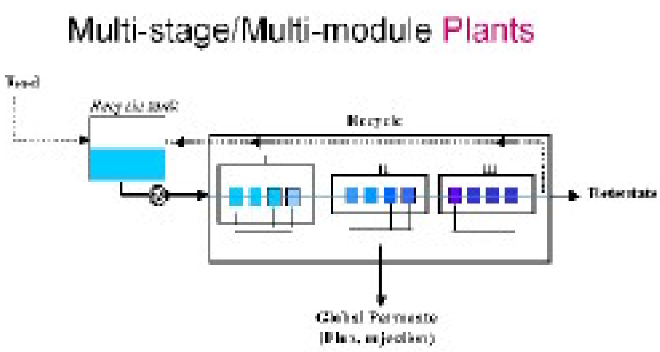
February 2-5, 2009
Cerphos (OCP), Casablanca, Morocco

Course Objectives

Faced with ever increasing demands for water worldwide, membrane technology is being called upon to play an increasingly important role in providing solutions to water supply problems. Reverse Osmosis (RO), and increasingly nanofiltration (NF), membrane processes are being used to design desalination plants to provide potable and irrigation water for costal populations, even in places where such technology was previously considered as being too costly. In very recent developments brackish water desalination is even being used on a large scale at inland sites (El Paso, Texas, USA). Hybrid systems coupling RO and NF are also being adopted in the design of integrated systems that are more economically efficient and environmentally friendly. If neither NF nor RO alone can provide a suitable solution, then hybrid NF/RO systems potentially lead to greater technical, economical, and environmental flexibility, opening up the possibility of tailored solutions for each type of industrial problem.

In order to accelerate the implementation of a given unitary or hybrid membrane technology, reliable process simulation is essential. This type of membrane process simulation depends intimately on an understanding of membrane transport theory and the ability to perform feasibility and optimization modeling. In this *intensive course* we first present the fundamentals of MF, UF, NF, and RO membrane transport theory and then explore in more detail how NF and RO membrane transport models can be incorporated into computer process simulation software, such as ***NanoFlux*** for NF and ***Desaltop*** for RO. These software tools are then used to illustrate how **feasibility and optimization simulation studies** can be carried out for real industrial desalination problems using NF and RO technology. Detailed presentations and hand-on simulation exercises will be provided for four important case studies: *1. the NF of brackish and highly concentrated brines; 2. seawater desalination, using a two permeate-staged NF process (**Long Beach, CA, USA**) 3. NF as pretreatment for RO (**Umm Lujj plant, Saudi Arabia**), 4. Design of RO plants for SW desalination as a non-linear optimization problem: minimizing energy costs while meeting performance goals.*

We explain how it is feasible to use advanced membrane transport modeling techniques to perform reliable NF and RO plant modeling for highly concentrated feeds in real-world situations where the composition and characteristics of the feed may change due to wide seasonal changes in salinity or temperature. These software tools put the full power of state-of-the-art membrane transport modeling at the fingertips of plant engineers and ultimately decision-makers.



Provisional program

I. Basic Principles of Pressure Driven Membrane Transport mechanisms

Introduction to membrane transport theory
- Multi-scale modeling: relevant length scales
- Transport in Porous and Dense media
- Pure water hydraulic permeability
- Mass and Charge Transfer; Osmotic Pressure
- Coupled Phenomenological Transport Equations and Transport coefficients

Macroscopic, mesoscopic, microscopic approaches to membrane transport: I
- Transport at the nanoscale in nanoporous membrane
- Connections with ionic transport in the ion channels of biological cell membranes
- Basic forces (interactions) and nanophysics
- Membrane solution permeability and solute Rejection/Passage; Hindered transport theory for neutral solutes

Macroscopic, mesoscopic, microscopic approaches to membrane transport: II
- Membrane solution permeability and ion Rejection/Passage for charged membranes: Hindered electro-transport theory
- Filtration Electrical potentials across charged membranes: Donnan interfacial potential; Streaming and Diffusion potentials

Gauging membrane and plant performance

- Solute Selectivity
- Concentration polarization
- Multi-scale membrane process modeling

II. NF: theory, modeling, simulations and applications

Nanofiltration: characteristics and applications, an overview

- Typical feed water types encountered in NF applications: ionic compositions, pH, neutral molecules; NF of toxic species
- Permeate, retentate, productivity, yield
- Modeling of Nanofiltration membrane transport as a multi-scale modeling problem: relevant length scales
- Ion transport in charged nanoporous media: from molecular dynamics simulations at the nanoscale to approximate meso- and macroscale models

Mesoscopic nanofiltration transport models

- Key parameters: 1. effective membrane pore size; 2. effective membrane charge density; 3. effective membrane thickness, including tortuosity and possible electrokinetic contributions; 4. dielectric constant of the membrane matrix and the nanopore water
- NF membrane performance (permeate flux and solute rejection) as a function of feed pressure, ionic strength, ion composition, temperature, and pH

***NanoFlux* NF simulation software**

- Multi-scale simulation algorithm: mass and charge balance
- Membrane characterization: 1. basic experimental protocol; 2. setting-up the internal *NanoFlux* membrane database
- Validating the transport model and the *NanoFlux* database using model and real solutions

***NanoFlux* Tutorial**

- Step-by-step approach to learning how to use *NanoFlux* and set-up a membrane database
- Computer Aided NF plant simulation, design, and optimization using the *NanoFlux* software
- NF plant simulations using *NanoFlux*: Detailed presentations of three important case studies, *1. the NF of brackish and highly concentrated brine; 2. seawater desalination, using a two permeate-staged NF process (Long Beach, CA, USA) 3. NF as pretreatment for RO (Umm Lujj plant, Saudi Arabia)*

III. SWRO: theory, modeling, simulations, optimizing and applications

Water quality, desalination process, membrane performances and plant design

- Typical water types encountered in RO applications: compositions, pH, temperature, RO of toxic species
- Norms of water quality for various applications: human consumption, irrigation, industries
- Comparison between the various desalinations process: distillation process (multi-effect vaporization, MSF), membrane process (electro-dialysis, RO)

- Membrane performances: types, selectivity, permeability, conversion, resistance, lifetime
- Typical plant design: intake, pretreatment, pressurizing, modules, post-treatment, power recovery

Modeling of RO membrane transport as a multi-scale modeling problem

- Membrane transport modeling: Kimura-Sourirajan, osmotic pressure, film theory, mass transfer coefficients, balance equations, Hagen-Poiseuille and Ergun models, module geometry, Boron transfer (Taniguchi model)
- Design modeling: RO multi-scale system in stages (assembly in reject series), RO multi-scale system in pass (assembly in product series), hybrid RO multi-scale system (stages and pass)
- Multi-scale modeling: basic equation system, permeate flow, permeate salinity, Boron permeate concentration, reject flow, reject salinity, Boron reject concentration
- Proposed algorithm for resolution and simulation

Design and membrane choice: Optimization of RO desalination plants as a non-linear optimization problem

- Linear and non-linear desalination problems, genetic algorithm.
- Mathematical model Algorithm: objective function, technical part, economic part (investment costs, operating costs, unit price of desalted water), decision parameters, constraint management
- Structure of the proposed algorithm: operators, mechanisms, generators

Computer Aided RO desalination plant design using *Desaltop*

- Simulation Algorithm
- Membrane database: membrane types and parameters, how to exploit the membrane database? How to introduce parameters?
- Genetic parameter regulating: initial population size, inter generation population size, generation number, probabilities, scaling coefficient
- Desaltop validation by twenty plant examples in various world areas: How can *Desaltop* be useful? How can *Desaltop* contribute to lowering the costs of RO desalination?

IV. Practical NF and RO modeling workshop: Hands-on desalination plant simulation and optimization using *NanoFlux* and *Desaltop* software

NF, RO and coupled NF-RO processes for desalination plants

- Review of *NanoFlux* and *Desaltop* for membrane process simulation.
- feasibility studies and design/performance optimization using *NanoFlux* for NF and *Desaltop* for RO
- Industrial applications concerning the valorization of NF and RO concentrates as raw material for the inorganic chemical industry

Hands-on NF and RO simulation exercises. I: Design and Optimization of unitary NF and RO membrane systems

- *NF of brackish and highly concentrated brine*
- *Seawater desalination, using a two permeate-staged NF process (Long Beach, CA, USA)*
- *NF as pretreatment for RO (Umm Lujj plant, Saudi Arabia)*

- Optimizing the RO process: selection of real case studies
- Simulation of desalination problems defined by the course participants

Hands-on NF and RO simulation exercises. II: **Using *NanoFlux* and *Desaltop* in tandem to simulate coupled NF/RO membrane processe**s

- Optimizing the NF pretreatment process (*NanoFlux)* to reduce power consumption and module number in RO plants (*Desaltop)*: : optimizing the membrane choice, design conception, and operation parameters.
- Optimizing the NF process to improve Boron elimination by RO processes
- Simulation of hybrid NF-RO desalination problems defined by the course participants

Course Instructors

Dr. John Palmeri, a CNRS Research Scientist and industry consultant from the *Laboratory of Theoretical Physics (LPT)* in Toulouse, France (CNRS, University of Toulouse), is a specialist in membrane transport modeling. Before moving to Toulouse in September 2006, he was previously the head of the "Transport Theory and Modeling" Group at the *Institut Européen des Membranes (IEM)* in Montpellier, France (CNRS, ENSCM, University of Montpellier). Since 1994 Dr. Palmeri has been working on the mathematical modeling of membrane transfer mechanisms with a special emphasis on the theory of electrolyte separations via nanofiltration. He has numerous ongoing collaborations with experimental groups focusing on ion and molecular transport mechanisms in NF membranes. He and his collaborators have published extensively in this field and also presented their work at numerous international conferences. He has taught courses on membrane transport theory at both the Masters and doctoral levels and also supervised several Ph.D. theses in this area. In this context he and his collaborators have developed nanofiltration models that have been incorporated into a multi-scale nanofiltration modeling software tool, ***NanoFlux***. This software, which is currently being commercialized by the CNRS, can be used to model industrial NF membrane processes. He is a member of the *European Membrane Society* and has worked as a consultant for companies working in the area of NF; he is also a coauthor of a book chapter covering NF simulation ["Computer Simulation of Nanofiltration, Membranes and Processes", H. Chmiel, X. Lefebvre, V. Mavrov, M. Noronha, J. Palmeri, in: Handbook of Theoretical and Computational Nanotechnology, edited by Michael Rieth and Wolfram Schommers, Volume 5, Pages 93-214, American Scientific Publishers, 2006].

Dr. Mehdi Metaiche, from the *Institut Européen des Membranes (CNRS, ENSCM, UMII), Montpellier, France and the Ecole Polytechnique d'Alger, Algeria**.*** Mehdi obtained his Ph.D. thesis in the RO process simulation in 2007**.** He currently works on optimizing membrane systems for RO and NF applications and their coupling in desalination plants, especially the optimization of membrane choice and plant design. He is currently concerned with making RO and NF desalination membrane systems more competitive in order to lower costs. He is the author of several computer codes, among which the ***Desaltop*** software, developed at the *Institut Européen des Membranes* (Montpellier, France) in collaboration with Dr. John Palmeri and Patrice David. This software is a basic tool for optimizing the design of RO water desalination plants via process simulation. He has published a score of articles on RO water desalination in scientific journals and in the proceedings of national and international conferences; he has also developed physical models describing RO and prepared academic teaching mimeographs in the water domain. He is a member of several scientific committees, the principal organizer of several scientist meetings, and a consultant for several Engineering offices in the area of water and environment.