SWRO (Desalination) Biofilm Remediation Technology Utilizing Centrifugal Micro-Fluids

Errol M. Glenn[1]

[1]University of California, Irvine, CA, USA

Abstract

Water-and-energy supply is a global issue of paramount importance. The demand for safe potable water is quickly exceeding the limits of natural regional water resources. Like oil, water is a finite resource; unlike oil, however, water has no alternatives. Water, energy and their environmentally sound solutions are interrelated; and of all the present-day environmental problems, those related to energy-and-water will have the worst long-term consequences if not resolved. Spiral-wound-reverse-osmosis (SWRO) desalination provides an alternative water resource that is both energy-efficient and highly-effective in removing particulate matter to well within the EPA's NPDWRs. Thermodynamically SWRO is an isothermal, reversible process that is closer to the lower energy limit than any other present-day desalination process. Real-world energy consumption, however, still accounts for +50% of the total operating cost of SWRO desalination plants. According to the U.S. Desalination and Water Purification Roadmap, membrane-permeability and fouling-resistance are primary economic drivers which translate directly to the energy footprint of these multi-megawatt facilities, whereby biofouling (marine-bacteria-biofilms) is considered the "Achilles Heel" of SWRO-membrane processes. , Concurrent research demonstrating the feasibility of dielectrophoresis as a biofouling remediation technology revealed that colloidal particles can be effectively levitated to a steady height above a SWRO-membrane. This study is still largely inconclusive in that only clay-colloids were examined; the electrokinetic properties of which are drastically different than those of marine-bacteria. Rather than developing potentially-cost-prohibitive SWRO-membrane embedded microelectrode arrays, the primary focus of the simulation studies being conducted (utilizing COMSOL Multiphysics 4.3; AC/DC, Microfluidics, & Particle-Tracing-Modules) are focused on developing a pretreatment-filtration device that is immediately upstream of the SWRO-membranes (d_p: 1-1000µm),. The mCD device is an ideal desalination feasibility study platform. In order to better quantitatively describe the performance characteristics of a mCD device, numerical simulation efforts are being conducted utilizing COMSOL Mulitphysics. The system of interest is comprised of 8 channels (50micron square cross-section, +20mm in radial length) rotating at 1rps, 10rps, and 100rps. The flow fields for various mCD-channel (angular) velocities is calculated using COMSOLs Rotating Machinery, Laminar Flow interface for single-phase flows. A "freeze" boundary condition will be applied to the outlets of each of the 8 channels whereby the specific flow cross-sectional makeups can be described using the Particle Tracing for Fluid Flow Module (to determine the cell distributions on the channel outlet flows and determine the 100%SeparationZone geometry). Preliminary simulation fluid flow results demonstrate good agreement with published research results. Research to be concluded prior to the October: (Study 1) Anisotropic diffusion of magnetotactic-bacteria (dynamic chemotaxis modeling w/ bi-directional,

flagellar-locomotion) using: a) magnetophoresis, and b) dielectrophoresis; (Study 2) Design improvements of microfluidic devices used for magnetophoretic separations, as well as follow-on studies to describe separation efficiencies for various solute-solvent concentrations (i.e. 10^n/mL; cells/milliliters/(solvent/solute). To further SWRO-membrane desalination as an energy-efficient, drought-proof and environmentally benign technology; it is herein proposed that cellular-bacteria-separations can be demonstrated utilizing the centrifugal-microfluidics (mCD) platform. Forecasting the system's separation effectiveness and subsequent energy-demand utilizing COMSOL Multiphyics is the most significant component of this technology's success. Furthermore, this novel demonstration of the mCD platform using COMSOL Mulitphysics can be applied to other applications such as clinical diagnostics, cancer research, and other flow-cytometry applications.

Reference

1. Water may be the next big thing. A. Weiss. New Haven Register. July, 2010.
2. Calvert White Paper: Unparalleled Challenge and Opportunity in Water. Calvert. Bethesda,MD. September, 2008.
3. Energy Issues in Desalination Processes. R. Semiat, Technion-Isreal Institute of Technology. May, 2008.
4. Desalination & Water Purification Research & Development. Sandia National Laboratories. January, 2003.
5. Biofouling: the Achilles heel of membrane processes.H. Flemming. Mulheim, Germany. August, 1997.
6. Dielectrophoretically intensified cross-flow membrane filtration. F. Du. Bremen, Germany. March, 2009.
7. Progress in electrohydrodynamics of soft microbial particle interphases. J. Duval. Cedex, France. December, 2009.
8. Prevention of colloidal membrane fouling employing dielectrophoretic forces on a parallel electrode array. S. Molla. Edmonton, Canada. March, 2005.

Figures used in the abstract

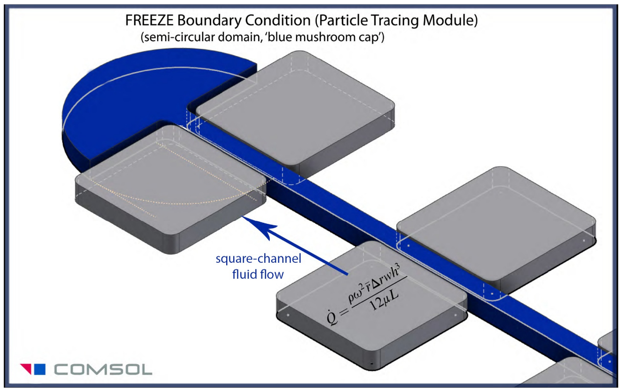

Figure 1

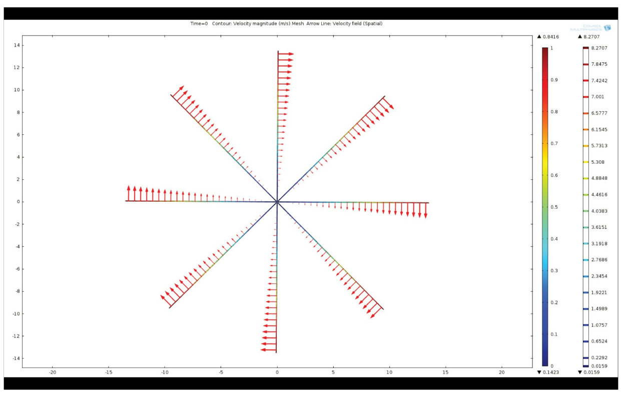

Figure 2

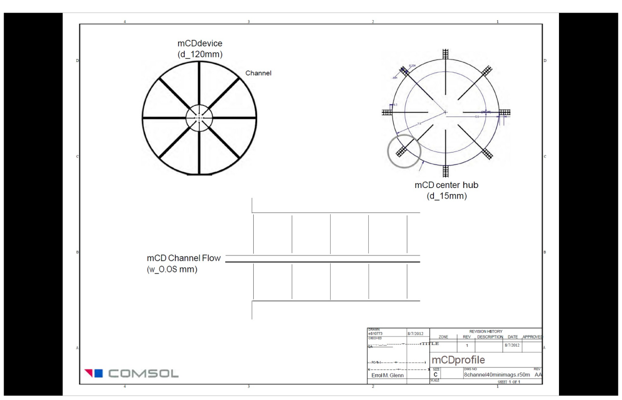

Figure 3

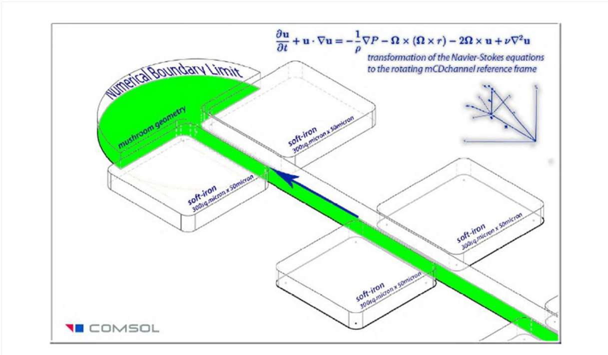
$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho} \nabla P - \mathbf{\Omega} \times (\mathbf{\Omega} \times r) - 2\mathbf{\Omega} \times \mathbf{u} + \nu \nabla^2 \mathbf{u}$
transformation of the Navier-Stokes equations
to the rotating mCDchannel reference frame
Numerical Boundary Limit
mushroom geometry
soft-iron
300sq.micron x 50micron
soft-iron
300sq.micron x 50micron
soft-iron
300sq.micron x 50micron
soft-iron
300sq.micron x 50micron
COMSOL

Figure 4