NAMS

The North American Membrane Society

2021

Convergence

Connecting Membrane Science with Societal Challenges

30th Annual Meeting
Estes Park, Colorado
Ridgeline Hotel

Aug 28 –Sep 2, 2021

Workshop Descriptions

Meeting Chairs:

Uwe Beuscher, W.L. Gore & Associates, Inc.
Yifu Ding, University of Colorado - Boulder
John Pellegrino, University of Colorado - Boulder

Measurement Methods for Membranes

Saturday August 28, 2021 8AM – 5PM

Lecturers:
Uwe Beuscher, ubeusche@wlgore.com, W.L. Gore & Associates, Inc.
Ryan Lively, ryan.lively@chbe.gatech.edu, Georgia Institute of Technology
John Pellegrino, john.pellegrino@colorado.edu, University of Colorado at Boulder

Abstract:

This workshop provides an overview of the entire field of membrane science, technology, and applications through measurements, and is therefore an excellent resource for novices with a technical background, as well as, seasoned veterans interested in broadening their scope (or having a refresher.) The workshop will provide a survey of the various physical and chemical properties of membranes (and membrane process characteristics) that are measured, and the equipment (instruments) and techniques used, along with their underlying principles. A mixture of classical, novel, and resource-intensive techniques are included.

Syllabus topics include: materials and structures; gas and liquid phase transport; mechanical and physical metrology techniques; porometry; surface and chemical measurements; visualization and scattering techniques; and special topics illustrating emerging characterization approaches. The workshop will finish with an industrial perspective segment that features a few invited panelists who will comment on how their organizations use membrane characterization to advance (or maintain) their business objectives.

Two weeks prior to the workshop a set of journal articles will be made available to the registrants. These articles will be used in class discussions. Also, all registrants will be asked to fill out a survey with questions and topics of particular interest to them.

The co-instructors combine many decades of membrane science and technology experience in industry, academia, and government. Their expertises include both polymeric and inorganic membranes as applied to gases, organic liquids, and water over a broad range of separations and filtration applications requiring both dense and porous materials. They have all actively applied advanced and classical characterization methods throughout their careers.

Uwe Beuscher is a Technical Leader at W.L. Gore & Associates, Inc., the world leader in fluoropolymer materials for a wide variety of applications. Dr. Beuscher received his Diplom-Engineer degree in Mechanical Engineering from RWTH Aachen (Germany) and his Ph.D in Chemical Engineering from Clemson University (U.S.A.). After joining W.L. Gore & Associates, Dr. Beuscher contributed for over 20 years to developments in a wide variety of separation applications including adsorption, catalysis, chromatography, polymer fuel cells, gas-liquid contactors, barrier materials, gas separation, liquid purification, and advanced microfiltration. Currently, Dr. Beuscher is leading the Gore Mercury Control System Team, which explores novel ways to remove Mercury and SO2 from flue gases and waste gas streams. Dr. Beuscher has authored or co-authored more than thirty technical papers, book chapters, and presentations. He has served on various advisory boards and as the president of the North American Membrane Society (NAMS).

Ryan Lively is an Associate Professor at the School of Chemical and Biomolecular Engineering at the Georgia Institute of Technology. His research is in the area of separations science and technology and focuses on creating improved materials and processes that enable low energy chemical separations. He has received a variety of awards for his research efforts including the 2020 Allan P. Colburn Award from the AIChE. He is currently the John H. Woody Faculty Fellow and serves as an Editor for the Journal of Membrane Science and on the North American Membrane Society's Board of Directors. In 2020, he was appointed as Director of the Center for Understanding and Control of Acid Gas-Induced Evolution of Materials for Energy (UNCAGE-ME), an Energy Frontier Research Center of the US Department of Energy. He has over 110 publications in the field of separations including articles in Science, Nature, and Nature Materials.

John Pellegrino founded this workshop in 1995 and has helped evolve it since then. He has held research and development positions at Rohm & Haas Co., duPont Inc., the National Institute of Standards and Technology (NIST), and Santa Fe Science and Technology Inc., and is currently a Research Professor in the Mechanical Engineering Department at CU-Boulder.

Membranes for Water Treatment & Reuse

Saturday August 28, 2021 8:00AM – 5:00PM

Lecturers:
Dibakar Bhattacharyya, University of Kentucky, DB@uky.edu
Isabel C. Escobar, University of Kentucky, Isabel.Escobar@uky.edu
Ben Weaver, Solecta Membranes, ben.weaver@solectamembranes.com

Abstract:
Membrane processes are finding wide applications ranging from water treatment to reactors to advanced bio-separations. Membranes are particularly useful for material recovery and for permeate reuse (such as, water recycle). The workshop is configured as a one day program of about 6 hours of lectures. Both desalination and toxic pollutant removal/destruction techniques will be discussed. The workshop topics include membrane selection criteria, practical information regarding configuration, performance and operating conditions of membrane technology applied to desalination of brackish and seawater, and wastewater reclamation systems, mixed-matrix membranes, and advanced functionalized/responsive membranes from metal capture to emerging pollutants (PFAS) detoxification. Membrane surface and pore functionalization approaches, reactive nanostructured for water detoxification will be part of the advanced membrane topics. The effects of feed water quality, pretreatment options, operating parameters and performance of membrane units and hybrid options will also be discussed. The workshop material will also include information on economics of membrane systems including drivers for membrane selection for various applications.

OUTLINE

Session 1 (Instructor: I.C. Escobar)
- Introduction to membrane theory
- Materials, configuration and performance

·Session 2 (Instructor: I.C. Escobar)
- Scaling and fouling phenomena
- Membrane Integrity and degradation

·Session 3 (Instructor: I.C. Escobar)
- Membrane water applications and pretreatment
- Membrane markets

·Session 4 (Instructor: D. Bhattacharyya)
- RO, NF, etc. for pollutants removal
- Graphene-based membranes and hybrid systems
- Valuable materials recovery and water reuse

·Session 5 (Instructor: D. Bhattacharyya))
- Functionalized and responsive membranes for water area
- Toxic metal capture, and emerging pollutant (PFAS) separations

·Session 6 ((Instructor: D. Bhattacharyya)
- Membranes with nanostructured catalytic materials
- Advanced membrane-based oxidation/reduction for organic pollutant detoxification

·Session 7 (Instructor: Ben Weaver)
- Module design and elements
- Drivers for membrane selection

Isabel Escobar is a Professor in the Department of Chemical and Materials Engineering at the University of Kentucky. In the field of membrane separations, she has been the PI of numerous membrane research projects, has one recently licensed patent on a breakthrough anti-biofouling feed spacer material. Isabel Escobar and her research group have published over 75 articles in peer-reviewed journals, and have made over 200 presentations at national/international conferences. She has edited two books, Sustainable Water for the Future—Water Recycling versus Desalination (ISBN: 9780444531155) and Modern Applications in

Membrane Science and Technology (ISBN: 9780841226180). Escobar Chaired the 2006 American Water Works Association (AWWA) Desalination Symposium Chair, Honolulu, Hawaii, 21-22 May 2006; the NAMS 2007 Annual Meeting Chair, Orlando, FL, 11-16 May 2007; and the NAMS 2012 Annual Meeting Chair, New Orleans, LA, 9-13 June 2012. With Dr. Jamie Hestekin of the University of Arkansas, Escobar co-Chaired the Engineering Conferences International: Advanced Membrane Technology VII in Cork, Ireland, 11-16 September 2016; and with Dr. Dibakar Bhattacharyya, she co-Chaired the NAMS 2018 Conference in Lexington, KY. In 2020, she Chaired the Second Pan American Nanotechnology (Pannano II) in Brazil, and she was the Co-Meeting Program Chair of the AIChE Fall Annual Meeting. In 2022, she will co-Chair the Gordon Research Conference: Membranes: Materials and Processes. In September of 2015, Escobar gave a TEDx talk on Worldwide Water Issues: https://www.youtube.com/watch?v=-wbHD77kMWE&app=desktop.

Dibakar Bhattacharyya (DB) is the University of Kentucky Alumni Chair Professor of Chemical Engineering, Director of the Center of Membrane Sciences, and a Fellow of the American Institute of Chemical Engineers. He was the past President of NAMS, and he was the past Chair of the Separations Division of AIChE. He is the Co-Founder of the Center for Membrane Sciences at the University of Kentucky. He has published over 230 refereed journal articles and 21 book chapters, 2 books and Kirk-Othmar Encyclopedia chapter on Reverse Osmosis, and has 9 (one utility patent pending, 2021) U.S. Patents (Functionalized Membranes, green Synthesis, and thermo responsive membranes). He has worked with several industries in projects dealing with wastewater, material recovery, water reuse, and membrane separations. Dr. Bhattacharyya has received a number of awards for his research and educational accomplishments, including the 2009 Gerhold Award from the AICHE Separations Division for his outstanding contributions in Membrane Separations Technology Development, 2004 Kirwan Prize for Outstanding Research accomplishments, Larry K. Cecil AIChE Environmental Division Award for outstanding membrane technology developments in the water related field, and the University of Kentucky Great Teacher (1984,1996, 2008) Awards three times. At the 2007 NAMS Annual Meeting, he was honored for his contributions in the area of functionalized membranes. He has edited a book on Responsive Membranes and Materials, published by John Wiley.

Ben Weaver graduated from University of California, Berkeley with a BS degree in Chemical Engineering. He has spent his 8+ year career in various roles supporting membrane technology. Ben began his membrane career at Hydranautics where he worked on applications and development of hollow fiber and spiral wound MF and UF products used for treatment of seawater, wastewater, surface and ground waters primarily for pretreatment to NF/RO and drinking water. He spent 2+ years working on the Encina Seawater Pilot in Carlsbad, CA, future home of a 50 MGD desalination plant. He worked on applications for ethanol production as well as produced and seawater treatment for the oil and gas industry. He then started working for Solecta (previously Nanostone Water, Ultura, and Sepro Membranes) in an applications and sales role primarily focusing on process applications in food and beverage, industrial waste waters and specialty applications in energy and oil markets.

Polymeric and Inorganic Membrane Materials and Membrane Formation

Saturday, August 28, 2021 8AM – 5PM

Lecturers:
Henk Verweij, Ohio State University, Verweij.1@osu.edu
Maria R. Coleman, The University of Toledo, maria.coleman6@utoledo.edu

Abstract:
This workshop includes synthesis and properties of polymeric and inorganic membranes.

MORNING SESSION
Inorganic Membranes: Henk Verweij
This session will cover the most important inorganic membrane types with an emphasis on transport properties of single- and multi-layer structures. After taking the work shop, participants will be able to quickly evaluate the design and viability of supported membrane concepts. The workshop is of interest for researchers, students, teachers, and project managers. It will be slow- paced with much participant interaction.

1. Overview (50'; 10' break).
   - Definitions, representative dense and porous morphologies, chemical composition and structure.
   - Application for gas and liquid filtration and separation, relation with pore size.
   - Characterization with electron microscopy, Kelvin radius methods, ellipsometry, and gas and liquid transport.
2. Transport properties (50'; 10' break, 25')
   - Membrane transport regimes vs pore size.
   - Meso- and macro-porous membrane liquid transport, ion rejection.
   - Meso- and macro-porous membrane gas transport.
   - Micro-porous and dense membrane transport.
   - Transport in composite membrane materials.
   - Treatment of overall multi-layer permeance.
3. Synthesis, colloidal and wet processing (25'; 10' break, 50').
   - Colloids and colloidal stability.
   - Nano-particle synthesis, particle dispersion, and removal of agglomerates.
   - Colloidal consolidation of membranes and supports.
   - Electroless deposition of metal components.
   - Defect control and abatement.
   - Drying phenomena and crack-free drying.
   - Conventional and rapid thermal processing.

AFTERNOON SESSION
Polymeric Membranes: Maria R. Coleman
The polymer membrane portion will provide an overview on material selection and fabrication techniques for production of polymeric membranes. The structures and separation properties of a variety of membranes for microfiltration, ultrafiltration, nanofiltration, reverse osmosis, gas separation will be presented. If workshop facilities allow, there will be a practical demonstration of membrane casting as well as opportunities to participate. It will include the following topics:

1. Material Selection:
2. Basic principles of polymer science, transport mechanisms in polymers, material selection for different membrane separation processes, membranesstructure/property relationships. Additional topics will include mixed matrix membranes and next generation membrane materials.
3. Formation of Polymer Membranes by Phase Separation:
4. Immersion precipitation, thermally- induced phase separation process, microporous membranes,

dense, thin-skinned asymmetric membranes.

5. Formation of Thin-Film Composite Membranes:
6. Solution coating processes, interfacial composite membranes, multilayer composites.
7. Membrane Modifications: Methodology for surface and bulk modification by chemical and plasma techniques.

Hendrik (Henk) Verweij received his BS and MS in 1975 from Delft University of Technology, and his PhD in 1980 from Eindhoven Technical University. Until 1991 he was a research scientist at Philips Research Laboratories where he studied the structure and formation of inorganic glasses, insulators, superconductors, and translucent ceramics. Verweij was professor in Chemical Engineering at Twente University until 2000. In 2001 he moved from the Netherlands to the USA to become professor at the Department of Materials Science and Engineering of the Ohio State University (OSU). He was recently appointed to OSU's Emeritus Faculty and Academy and as a Nanjing Tech University Distinguished Professor and Foreign Expert. Verweij's expertise includes colloid & interface chemistry, solid state thermodynamics, sorption and transport in dense and porous matter, wet-chemical and colloidal synthesis, and process control. His current research topics are inorganic membranes for CO_2, H_2, and O_2 separation and water treatment, thin film solid oxide fuel cells and electrochemical O_2 pumps.

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Membrane modeling and simulation

Sunday August 29, 2021 8AM – 5PM

Lecturers

Mahdi Malmali, Mahdi.Malmali@ttu.edu, Texas Tech University
Nitish Mittal, Nitish.Mittal@exxonmobil.com, ExxonMobil Corporation
Udit Gupta, U.Gupta@psenterprise.com, Process Systems Enterprise

Abstract

This workshop provides the participants an opportunity to connect technical knowledge with modeling practices. We will start the workshop with a detailed introduction of the fundamentals of the transport mechanism in membrane and reviewing the key modeling parameters in modeling. The participants will be then introduced to the simulation software environment. The rest of the workshop will be mostly focused on hands-on practice examples using simple, but insightful, membrane problems. The simulation software will be available for the registrants through a cloudshare environment. Participants will be trained to create a process-level membrane model and conduct a sensitivity analysis using the software features. The developed model will be later imported into a process flowsheet. At the beginning of each hands-on session, a partial model will be provided. A fully-fledged model will be provided at the end of each session, which will be used in the subsequent session. A tentative outline of the workshop is provided below.

Notes:

- Participants should bring their own laptops. For hands-on sessions, participants will connect to a cloudshare environment through an online browser (e.g. Google Chrome, Mozilla, Firefox, etc). The simulations will be run on a remote cloudshare computer.
- Two weeks prior to the workshop, a review package will be made available to participants. This package includes slides, journal articles, and a summary note about the topics that will be discussed in the workshop.
- One week prior to the workshop, a survey will be forwarded to participants. The purpose of this survey is to determine the expertise of the participants in the modeling and simulation packages. Instructors will use this survey to familiarize themselves with the needs and expectations of the participants.
- We plan to use PSE's gPROMS Advanced Process Modeling Software as the simulation platform as PSE has agreed to provide free software licenses and cloudshare platform for the workshop. However, the topics and subjects covered in this workshop will be applicable to other software packages.

Outline

- Session-1: Transport mechanism and models

  This session will summarize the mechanism of membrane permeation, concept of driving force, and key modeling parameters in different type of membrane materials, and applications. We will compare various mechanisms, their implication on modeling, and scope of model transferability from one application to the other.
- Session-2: Significance of modeling and synergy with experiments

  We will discuss the advantages and limitation of the modeling, and how the synergy of experiments and modeling can be used to tackle a physical problem. We plan to demonstrate this by using a simple, but insightful, membrane problem that we plan to solve within this workshop. We will discuss how to convert the problem into equations relating key membrane parameters (e.g. permeability, selectivity, etc.), operating conditions (pressure and temperature), and required performance output (recovery, purity, etc.), and the role of experiments and modeling to obtain these quantities.
- Session-3: Introduction to Model Simulation environment

  Instructors will introduce the participants to the basic capabilities of the simulation software, such as, overview of the layout, how to write equations, simulate the model, and access the results. For this workshop, we will be using PSE's gPROMS Advanced Process Modeling Software as the simulation

platform.

- Session-4: Developing a fundamental membrane model
  During this session, participants will use the equations developed in Session-2 and incorporate them into the simulation software. In this hands-on activity, instructors will focus on important aspects of the simulation, such as membrane and modeling equations - rather than intricacies of the software itself. Hence, a partially-built model/template will be provided for the participant as the starting point.
- Session-5: Developing a process membrane model
  This session will cover the equations for integrating a membrane fundamental model into a process-level model. This will be a combination of demonstration and hands-on exercises. We will demonstrate how to implement a distributed model) ordinary differential equation) within the simulation environment. This partially built model will be provided as a template for hands-on exercise focusing on plug-flow model implementation. The concept of stage-cut and boundary layer resistance will be briefly discussed.
- Session-6: Sensitivity analysis and design specification
  During this session, we will teach how to use the developed model to study the effect of various operating conditions and key membrane parameters. Some of the software features will be used to scan through the output space/vector for the provided input space/vectors. Further, we will show how to back calculate the key membrane parameters or operating conditions for a given design specifications. The completed model from the previous exercise will be provided for this activity.
- Session-7: Using membrane process model within a flowsheet
  In this session, we will demonstrate how to use a membrane model in a process flowsheet connecting reactors and other separation units.

Dr. Mahdi Malmali is an assistant professor of Chemical Engineering at Texas Tech University. He received his M.S. in Chemical Engineering from Sharif University of Technology (2010) and his Ph.D. in Chemical Engineering from the University of Arkansas (2014). Dr. Malmali joined the Chemical Engineering and Materials Science department at the University of Minnesota as a postdoctoral research associate (2015-2017). Dr. Malmali joined Texas Tech University in 2018. His research interests are membrane-based separations and reaction engineering. Dr. Malmali utilizes process customized modeling and simulations for the energy analysis of reaction and separation processes.

Dr. Nitish Mittal is a Senior Research Engineer in Chemical Process Research division of ExxonMobil Corporation. Before joining ExxonMobil in 2018, he graduated with a Ph.D. in Chemical Engineering from the University of Minnesota where he developed fundamental and process model for inorganic membrane separation with applications in gas, chemicals and biofuels. Dr. Mittal has published seven peer-reviewed papers in high-impact journals and has been invited to present at international membrane conference venues including International Congress on Membranes & Membrane Processes and Gordon Research Conference Membranes: Materials and Processes.

Dr. Udit Gupta is a Consultant Engineer in Energy & Chemicals Business Unit of Process Systems Enterprise (PSE). Before joining PSE in 2019, he graduated with a Ph.D. in Chemical Engineering from the University of Minnesota where he developed microkinetic models for complex reaction networks using automated network generation. He also did postdoctoral research at University of Delaware developing modules for modeling chemical reaction systems. Dr. Gupta has published four peer- reviewed papers in high-impact journals. Dr. Gupta has been delivering technical training for PSE's gPROMS Advanced Process Modeling Software to various Energy & Chemicals clients as well as conducting workshop at AIChE 2019.

Membrane Gas Separations

Sunday August 29, 2021 8AM – 5PM

Lecturers:

Benny Freeman, University of Texas at Austin, freeman@che.utexas.edu

Glenn Lipscomb, The University of Toledo, glenn.lipscomb@utoledo.edu

Tim Merkel, MTR Inc., tim.merkel@mtrinc.com

Abstract:

This workshop will cover the entire spectrum of membrane-based gas and vapor separations: from the materials science of gas separation membranes and the fundamentals of membrane transport to the design and economics of industrial gas separation applications. This workshop should be of interest to membrane researchers as well as membrane practitioners.

Outline:

1. Materials: Freeman, 8-10:15 AM
    - Material science of gas separation membranes and transport mechanisms
2. Break: 10:15-10:30 AM
3. Modeling Gas Sorption and Diffusion: Sarti, 10:30-11:15
4. Modules: Lipscomb, 11:15-12 and 1-2:30 PM
    - Module Manufacture (patent review)
        - Scroll/spiral wound module formation
        - Fiber bundle/tubesheet formation and types
        - Header and case design
    - Module Performance
        - Basic design equations for gas separations
        - Hollow fiber versus spiral wound
        - Module inefficiencies: fiber size/property variation & poor shell flow distribution
5. Break: 2:30-2:45 PM
6. Applications: Merkel, 2:45-5 PM
    - Basics of Gas Separation System Design
        - Pressure ratio
        - Multi-step and multi-stage configurations
    - Gas Separation Industry: History and Overview
    - Air Separation
        - Nitrogen - enriched Air
        - Oxygen - enriched Air
    - Hydrogen Separation
    - Natural Gas Separation
        - Acid Gas Removal
        - Nitrogen Removal
        - NGL Recovery/Fuel Conditioning
    - VOC Removal/Recovery
    - Emerging Applications

Membranes in Bioprocessing

Sunday August 29, 2021 8:00 AM- 5PM

Lecturers:
John Cyganowski, MilliporeSigma, John.Cyganowski@emdmillipore.com
Herb Lutz, MilliporeSigma, herb.lutz@milliporesigma.com

Abstract:
This workshop includes the use of membranes in bioprocessing for clarification, harvest, sterilization, virus retention, and protein concentration and buffer exchange. It will also include some samples of different devices and materials as well as an experimental demonstration of TFF.

MORNING SESSION 8AM-12 noon- Intro & Normal Flow Filtration

1. Overview (30').
   - History
   - Membrane types.
   - Bioprocess Applications & role of membranes.
2. NFF- clarification (30')
   - Membranes, devices, applications, operation
   - Pmax selection & sizing
   - Selected implementation topics
3. NFF- sterilization (20'break, 50').
   - Membranes, devices, applications, operation.
   - Vmax selection & sizing.
   - Validation & Integrity testing.
4. NFF- virus retention (50').
   - Membranes, devices, applications, operation.
   - Vmax selection & sizing.
   - Validation & Integrity testing

AFTERNOON SESSION 1PM-5PM- Tangential Flow Filtration & Wrap-up

5. TFF- clarification (50'; 20' break).
   - Membranes, devices, applications, operation
   - Selection & sizing
   - Selected implementation topics
6. TFF- Protein concentration and diafiltration (80'; 10' break).
   - Membranes, devices, applications
   - Operation- UF & DF
   - Selection & sizing
   - Selected implementation topics
7. Wrap-up (30').
   - Manufacturers, economics, references, selected topics

After taking the workshop, participants will be able to define process requirements and select among different filters and size and optimize their operation. The workshop is of interest for membrane researchers, process development scientists, plant operators, and technical operations.