NEW JERSEY INSTITUTE OF TECHNOLOGY, NEWARK, NJ
OTTO H. YORK DEPARTMENT OF CHEMICAL AND
MATERIALS ENGINEERING

ChE 710: Advanced Membrane Separation Processes, Fall 2024 (September 5 onwards)

Lecture Time:	Thursday, 6:00 pm to 8:50 pm (112 Tiernan)
Instructor:	Professor K. K. Sirkar, (Tel. No.) (973) 596-8447, Rm. 371T
Email Address:	sirkar@njit.edu
Office Hours:	Wednesday, 4:30-6 pm

Course Outline: This course will provide advanced treatments of the science, technology, engineering analysis and design of the following and related membrane separation processes: reverse osmosis, nanofiltration, ultrafiltration, dialysis, electrodialysis, Donnan dialysis, liquid membrane permeation, microfiltration, gas permeation through polymeric membranes, pervaporation, membrane-based equilibrium separation processes, membrane contactors, membrane reactors and hybrid membrane processes. Significant coverage of membrane structure/function and device design for various applications as well as membrane fabrication will be provided. Examples of relevance to Biomedical, Biopharmaceutical, Chemical, Pharmaceutical and Water Treatment industry will also be provided.

Prerequisites: Graduate courses ChE 624, 626 or their equivalents.

Textbooks:

1. I will share a variety of notes for each lecture with the students.

2. Many of the modeling developments will be available in the book: Kamalesh K. Sirkar, "Separation of Molecules, Macromolecules and Particles: Principles, Phenomena and Processes", Cambridge University Press, 2014. Identified as (Sirkar).

3. W.S.W. Ho and K.K. Sirkar (eds.), Membrane Handbook, 1992, Chapman and Hall, NY; Springer, Boston, 2001, 2012. This book has basic information for most of the membrane processes.

Lecture Details:

One week: Introduction to membranes, membrane structure (and fabrication) and membrane separation processes. General characteristics of membrane separation processes (Chapter 1 in Membrane Handbook (2012); Chapter 1 in Meares (1976); Chapters 1 and 2 in Rautenbach and

	Albrecht (1989); Chapters 1 and 2 in Mulder (1997); Chapter 1 in Crank and Park1(968); Chapter 3, Sirkar (2014)).
One and half weeks:	Reverse osmosis. Principles. Membrane transport. Concentration polarization. Geometrical configurations of RO modules. Design of tubular, hollow fiber and spiral wound modules. Applications. Forward osmosis. Pressure retarded osmosis. Nanofiltration. (Ho and Sirkar, Chapters 21-25 (1992, 2001); Merten, pages 1-30, 55-58, 86-90, 93-105, 130-137, 145, 160-184; Sourirajan (NRC) pages 199-200 and first two chapters; Spiegler and Kedem (1966); Spiegler's book, Chapter on Hyperfiltration; Sourirajan (NRC) Chapter 4, Chapter 27 (by J.W. McCutchan); Chapter 4 by Harris et al. in Meares's book Membrane Separation Processes; Soltanieh and Gill (1981)). H. Wijmans and R. W. Baker, Journal of Membrane Science, vol. 107, 1-21(1995). Sirkar: Book Sections, 3.4.2, 5.4.1, 6.3.3.3, 7.2.1.2.
One and half weeks:	Principles of Ultrafiltration. Transport in UF membranes. Solute retention in microporous and diffusive UF. Gel polarization. MEUF. UF module configurations. Design of UF modules. UF processing schemes and applications (Ho and Sirkar (eds.), Chapters 26-30 (1992, 2001); Prog. in Sep. and Purification, Vol. 1, E.S. Perry (ed.); article by A. Michaels; Chapter 3 by W.F. Blatt in Meares's book, Membrane Separation Processes; pages 47-96 by Blatt et al. in Flinn, Membrane Science and Technology (1970)). Also Sirkar: Book Sections, 3.4.2.3, 5.4.2, 6.3.3.2, 6.4.2.1, 7.2.1.3.
One week:	Principles of dialytic separation. Batch and continuous dialyzer analysis. Effect of secondary chemical equilibria. Hemodialysis. Hemodiafiltration. Buffer exchange (Ho and Sirkar (eds.), Chapters 11-15 (1992, 2001); Meares, Chapter 2, pages 39-77; article by Sprigg and Li; Karger, Synder and Horvath, pages 486-491; Michaels (1966)). Also Sirkar: Book Sec. 3.4.2.4, 4.3.1, 5.4.3, 8.1.7.1, 8.2.4.1.
Two weeks:	Principles of electrodialysis through ion exchange membranes. Types of ED. Electrodialytic transport, selectivity and polarization. Stack resistance. Design of ED stack. (Ho and Sirkar (eds.), Chapters 16-20 (1992, 2001); Spiegler (1966), Chapter 6; pages 199-289 by Schaffer and Mintz; Meares, Chapter 6; pages 259-293 by Solt; Li, Recent Developments in Sep. Sci., Vol. 2, pages 157-170, article by McRae and Leitz). Principles of Donnan dialysis. Transport and boundary layer considerations. Role of chemical reactions. Applications. References to be given in class. Also Sirkar: Book Sections 3.4.2.5, 4.3.2, 5.2.6, 8.1.7.2.
One week:	Separation through immobilized (supported) liquid membrane, emulsion liquid membrane and hollow fiber contained liquid

membranes. Equipment for considerations for LMSP. Process design. Facilitation. Applications. (Chapters 36-40, 42 and 44 in Membrane Handbook (1992, 2001); Meares, Chapter 9, pages 327-350 by Chan and Li; Casamatta et al., Chem. Eng. Sci. (1978), Vol 33, 145-152; Casamatta et al., AIChE J., 24 (6), 945 (1978); Li, Recent Developments in Sep. Sci., Vol. 1, article on Liquid Membrane Water Treating by N.N. Li and A.L. Shrier). Also Sirkar: Book Sections 5.4.4, 8.1.8.

One week: Microfiltration principles. Types. Cross-flow and dead-end microfiltrations. Theory. Applications. Design (Membrane Handbook, Chapters 31-35.). Also Sirkar: Book sections 6.3.1.4, 6.3.3.1, 7.2.1.4.

One and a half weeks: Gas permeation separation through polymeric membranes. Gaseous diffusion separation. Role of defects. Separation of vapors. Dual sorption. Permeator arrangements. Design of permeators. Cascades/separations schemes. Applications. (Ho and Sirkar (eds.), Membrane Handbook, Chapters 2-6 (1992, 2001); Pan and Habgood, I&EC Fund., 13, 323 (1974); Meares, Chapter 8, pages 295-326 by Stern; Li, Recent Developments in Sep. Sci., pages 107-156 by Rogers, Fel and Li; Pratt, Countercurrent Separation Processes, Chapter on Gaseous Diffusion). Also Sirkar: Book Sections 3.4.2.2, 3.4.2.4, 4.3.3, 5.4.5, 6.3.3.5, 6.4.2.2, 7.2.1.1, 8.1.9, 8.2.4.2.

One week: Pervaporation. Mechanism. Azeotrope separation. Applications. (Membrane Handbook, Chapters 7-10 (1992, 2001); Greenlaw et al., J. Membrane Sci., 2, 141 (1977), etc.; Huang, Pervaporation Membrane Separation Processes (1991); Mulder, Basic Principles of Membrane Technology, pages 234-244 (1991)). Also Sirkar: Book Sections 3.4.2.2, 6.3.3.4.

One and a half weeks: Microporous/porous membrane based solvent extraction, gas absorption/stripping, membrane distillation, gas membrane and membrane adsorption. (Chapters 41 and 46 in Membrane Handbook). Also Sirkar: Book Sections 3.4.3, 8.1.2.1, 8.1.2.2.1, 8.1.4.

One week: Membrane reactors. Types. Analysis of equilibrium shift. Reactors. Reduction of product inhibition in bioreactors. Cell culture devices. (Chapter 43, Membrane Handbook (1992); plus other references to be given in class.). Hybrid membrane processes.

Recommended Reference Books (kept in reserve section of library)

1. S.T. Hwang and K. Kammermeyer, Membranes in Separation, Techniques of Chemistry, Vol. VII, Wiley-Interscience (1975). Reprinted, 1984 by R.E. Krieger Publishing Company, Inc., Melbourne, FL 32902.

2. P. Meares (ed.), Membrane Separation Processes, Elsevier, Amsterdam (1976).

3. K.S. Spiegler (ed.), Principles of Desalination, Academic (1966). Pages 345 onwards, "Hyperfiltration"; 2nd edition (1979) Part A Chapter 6, pages 257-357 for ED.

4. S. Sourirajan (ed.), Reverse Osmosis and Synthetic Membranes, NRC, Ottowa, Canada (1977).

5. R. Rautenbach and R. Albrecht, Membrane Processes, Wiley (1989).

6. M. Mulder, Basic Principles of Membrane Technology, 2nd Ed., Kluwer/Springer (1997).

7. R.Y.M. Huang (Ed.), Pervaporation Membrane Separation Processes, Elsevier Science Publishers, New York (1991).

8. J. Crank and G.S. Park, Diffusion in Polymers, Academic Press (London), 1968.

Recommended References for Further Reading (kept in the reserve section of library)

1. Progress in Separation and Purification, Vols. 1, 2, 3 and 4, E.S. Perry and others (eds.), 1968 onwards, Interscience.

2. S. Sourirajan, Reverse Osmosis, Logos Press, London (1970).

3. U. Merten, Desalination by Reverse Osmosis, MIT Press (1966).

4. Separation and Purification Methods, Vols. 1 and 2, E.S. Perry and C.J. Van Oss (eds.), Marcel Dekker (1972).

5. C.J. King, Separation Processes, 2nd Edition, McGraw-Hill (1980).

6. H.R.C. Pratt, Countercurrent Separation Processes, Elsevier (1967).

7. Recent Developments in Separation Science, Vols. 1, 2, 3A, 3B, N. Li (ed.), CRC Press (1972) (1975) (1977).

8. J.E. Flinn (ed.), Membrane Science and Tech., Plenum Press, New York (1970).

9. R.W. Rousseau (ed.), Handbook of Separation Process Technology, Wiley, New York (1987).

References 10 to 21 are kept in a bound volume in the reserve section of the library.

10. J.E. Flinn and R.H. Cherry, Jr., CEP Symp. Series, Vol. 65, No. 91, p. 90-97 (1968).

11. K.S. Spiegler and O, Kedem, Desalination, 1, 311 (1966).

12. M. Soltanieh and W.N. Gill, Chem. Engg. Commun., 12, (1981).

13. J.W. McCutchan and V. Goel, Desalination, 14, 57 (1974).

14. M.R. Doshi, W.N. Gill and V.N. Kabadi, AIChE J., 23 (5), 765 (1977)

15. A.S. Michaels, Trans. Am. Soc. Art. Int. Org., XII, 387 (1966).

16. W.J. Ward, AIChE J. 16 (3), 405 (1970).

17. A.M. Hochhauser and E.L. Cussler, AIChE Symp. Ser., Vol. 71, No. 152 (1975).
18. G. Casamatta, D. Bouchez and H. Angelino, Chem. Eng. Sci., 33, 145 (1978).

19. G. Casamatta, C. Chavarie and H. Angelino, AIChE J., 24 (6), 945 (1978).

20. C.Y. Pan and H.W. Habgood, I&EC Fundamentals, 13, 323 (1974).

21. F.W. Greenlaw, W.D. Prince, R.A. Shelden and E.V. Thompson, J. Membrane Sci., 2, 141 (1977).

Examinations and Grading

There will be two written open-book exams, each lasting about 90 min + to 120 min and a final written open-book exam for 180 min.

Possible Exam Dates:	Oct 10 or 17	(Exam 1)
	Nov 14 or 21	(Exam 2)
	Dec 19 (?)	Final Exam

A term paper/project may be required. Grading distribution without the term paper is as follows: Exam 1 (30%), Exam 2 (30%), Final Exam (40%). If term papers are used, grade distribution will be changed. Grading will be on the curve. There is a low probability of very short quizzes.