Fuel Cell Technology, MAE 410/510, Spring 2004

Dr. Ramesh K. Shah

Contact: E-mail: rks3@eng.buffalo.edu; Cell Phone: 390-9103 (will be activated during the week of January 19).

Office Hours will be during 4:30 – 5:30 PM on Mondays and Fridays in 327 Jarvis.

Course Website: It will be prepared soon and will be informed.

Class Timings: Mondays and Fridays 3:00-4:30 PM. The first lecture will start on January 12, 2004.

Prerequisites: A first course in Thermodynamics and Chemistry.

Course Description: Fuel cell technology is an emerging technology for electric power generation for stationary, mobile and portable power applications. Fuel cell, the heart of this technology, is an electrochemical device in which hydrogen and oxygen react in the presence of catalyst and produces electricity, heat and water. The major advantages of fuel cell systems are higher energy conversion efficiencies, low emissions and negligible noise. In this course, after fuel cell technology basics and operating principles, fuel cell performance will be briefly described from energy and thermodynamic viewpoints. Subsequently, the following major types of fuel cells will be discussed: polymer electrolyte membrane fuel cell (PEMFC), Direct methanol Fuel Cells (DMFC), Alkaline Fuel Cells (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). The emphasis will be the performance behavior, analysis and modeling. Subsequently, the balance of the fuel cell power plant, thermal system design and analysis will be discussed that affect the power generation. Finally, the components needed, issues related, and pertinent analysis will be covered to delivering electric power generated from the fuel cell.

Course Objectives: Provide thorough understanding of performance characteristics of fuel cell power plant and its components. Outline the performance and design characteristics and operating issues for various fuel cells. Discuss the design philosophy and challenges to make this power plant economically feasible. The design and analysis emphasis will be on the thermodynamics and electrochemistry. Thus at the successful end of the course, the students will have sufficient knowledge for working in a fuel cell industry or R&D organization.

Outcomes: By the conclusion of this course, each student should

- Apply know-how of thermodynamics, electrochemistry, heat transfer, and fluid mechanics principles to design and analysis of this emerging technology.
- Have thorough understanding of performance behavior, operational issues and challenges for all major types of fuel cells.
- Identify, formulate, and solve problems related to fuel cell technology keeping in mind economic viability.
- Use the techniques, skills, and modern engineering tools necessary for design and analysis of innovative fuel cell systems.
- Understand the impact of this technology in a global and societal context.
- Develop enough skills to design systems or components of fuel cells.
- Be ready to begin a career as an engineer in companies developing fuel cell components and systems.

Textbook: ***Fuel Cell Systems Explained*** by James Larminie and Andrew Dicks, Second Edition, John Wiley, New York, 2003, ISBN 0-470- 84857-X.

Homework, Exams and Grading: There will be one homework every week, assigned on Monday and to be handed completed homework on the following Monday. We will use a team approach for homework. Three students together will submit one homework solution. For solution of each problem in a given homework, the student who prepared the solution should sign and clearly write the name with that problem. This team is supposed to discuss the subject matter and discuss the solution before preparing the solution so that they will learn more on the theory and the course content. There will be one midterm and one final exam. There will be no makeup exams. Homework: 25%; Midterm: 25%; Final 35%; Project 15%.

Project: A group of 5 students will be required to prepare a project on any aspect of Fuel Cell components, systems or technology with a report of 10 pages (single-spaced) maximum including figures and tables of reasonable size (like in a texbook and not too large).

Reference Material

E-Books

1. Fuel Cell Handbook by EG&G Services, October 2000: http://www.fuelcells.org/fchandbook.pdf
2. Status and Prospects of Fuel Cells as Automobile Engines A Report of the Fuel Cell Advisory Panel, July 1998: http://arbis.arb.ca.gov/msprog/zevprog/fuelcell/fuelcell.htm
3. Fuel Cells for Portable Power: Markets, Manufacture and Cost, January 2003. http://www.usfcc.com/download_a_file/download_a_file/USFCC-Portable-Power- Market-Study.pdf

Other Fuel Cell Books:

1. A.J. Appleby and F.R. Foulkes, *Fuel Cell Handbook*, Von Norstrand Reinhold, New York, 1989.
2. A.J. Bard, and L.R. Faulkner, *Electrochemical Methods: Fundamentals and Applications*, 2nd ed., Wiley, New York, 2001.
3. L.J. Blomen, *Fuel Cell Systems*, Plenum Publishing Corporation, New York, NY, 1994.
4. L.J.M.J. Blomen and M.N. Mugerwa, Editors, *Fuel Cell Systems*, Plenum Press, New York, 1993.
5. J. O'M. Bockris and S. Srinivasan, *Fuel Cells: Their Electrochemistry*, McGraw-Hill, New York, 1969.
6. M. Corbett, *Opportunities in Advanced Fuel Cell Technologies* V1 - Stationary Power Generation 1998-2008, Kline & Company, Inc., Fairfield, NJ, 1998.
7. G. Hoogers, Editor Fuel Cell Technology Handbook, CRC Press, Boca Raton, FL, 2003.
8. T. Koppel, *Powering the Future: The Ballard Fuel Cell and the Race to Change the World*, John Wiley & Sons, 1999.
9. K. Kordesch and G. Simander, *Fuel Cells and Their Applications*, VCH Publishers, Weinheim, Germany, 1996.
10. A. McDougall, *Fuel Cells*, John Wiley, New York, 1976.
11. N.Q. Minh and T. Takahashi, *Science and Technology of Ceramic Fuel Cells*, Elsevier Science, New York, 1995.
12. J.S. Newman, *Electrochemical Systems*, 2nd ed., Prentice Hall, 1991.
13. G. Prentice, *Electrochemical Engineering Principles*, Prentice Hall, 1991.
14. G. Sandstede, Editor, *From Electrocatalysis to Fuel Cells*, University of Washington Press, Seattle, 1972.
15. R. Stobart, Editor, Fuel Cell Technology for Vehicles, PT-84, Society of Automotive Engineers, Pittsburgh, PA, 2001.

16. W. Vielstich, A. Lamn and H.A. Gasteiger, Editors, *Handbook of Fuel Cells: Fundamentals, Technology and Applications*, Four Volumes, John Wiley, New York, 2003.

Some General References on Fuel Cell Types

1. L. Carrette, K.A. Friedrich and U. Stimming, Fuel Cells – Fundamentals and Applications, *Fuel Cells*, Vol. 1, pp. 5-39, 2001.
2. P. Costamagna and S. Srinivasan, Quantum jumps in the PEMFC science and technology from 1960s to the year 2000 – Part I. Fundamental scientific aspects, *Journal of Power Sources*, Vol. 102, pp. 242-252, 2001.
3. P. Costamagna and S. Srinivasan, Quantum jumps in the PEMFC science and technology from 1960s to the year 2000 – Part II. Engineering, Technology development and application aspects, *Journal of Power Sources*, Vol. 102, pp. 253-269, 2001.
4. M. Baldauf and W. Preidel, Status of the development of a direct methanol fuel cell, *Journal of Power Sources*, Vol. 84, pp.161-166, 1999.
5. A. Bauen and D. Hart, Assessment of the environmental benefits of transport and stationary fuel cells, *Journal of Power Sources*, Vol. 86, pp. 482-494, 2000.
6. M. Cassir and C. Belhomme, Technological applications of molten salts: the case of the molten carbonate fuel cell, *Plasma & Ions*, Vol. 1, pp. 3-15, 1999.
7. S. Gottesfeld, Polymer electrolyte fuel cells, *Advances in Electrochemical Science and Engineering*, Vol. 5, Eds. R. C. Alkire, et al., Wiley-VCH, pp. 195-301, 1997.
8. Hammou, Solid oxide fuel cells, *Advances in Electrochemical Science and Engineering*, Vol. 2, Eds. H. Gerischer and C.W. Tobias, et al., Wiley-VCH, pp. 88-139, 1992.
9. K. Hemmes, G. Lindbergh, J. R. Selman, D. A. Shores, and I. Uchida, *Carbonate Fuel Cell Technology*, PV 99-20, Honolulu, Hawaii, Fall 1999, Published by The Electrochemical Society, Inc., 10 South Main Street, Pennington, NJ, 08534; Tel: 609-7371902; website: www.electrochem.org
10. W. Kast and C.-R. Hohenthanner, Mass transfer within the gas-phase of porous media, *Int. J. Heat Mass Transfer*, Vol. 43, pp. 807-823, 2000.
11. L. Ma, C. Jiang, A.A. Adesina, D.L. Trimm, M.S. Wainwright, Simulation studies of Autothermal reactor system for H_2 production from methanol steam reforming, *The Chemical Engineering Journal*, Vol. 62, pp. 103-111, 1996.
12. N. Q. Minh, and T. Takahashi, *Science and Technology of Ceramic Fuel Cells*, Elsevier, Amsterdam. 1995
13. M. Neegart and A.K. Shukla, A high performance phosphoric acid fuel cell, *Journal of Power Sources*, Vol. 102, pp. 317-321, 2001.
14. S. Rowshanzamir and M. Kazemeini, A new immobilized-alkali H_2/O_2 fuel cell, *Journal of Power Sources*, Vol. 88, pp. 262-268, 2000.
15. S.C. Singhal, Advances in solid oxide fuel cell technology, *Solid State Ionics*, Vol. 135, pp. 305-313, 2000.
16. O. Yamamoto, Solid oxide fuel cells: fundamental aspects and prospects, *Electrochimica Acta*, Vol. 45 pp. 2423-2435, 2000.
17. H. Yokokawa and S.C. Singhal, Editors, *Solid Oxide Fuel Cell 7*: Proceedings of the 7th International Symposium, Published by the Electrochemical Society, 10 South Main Street, Pennington, NJ, 08534; Tel: 609-7371902; website: www.electrochem.org (Refer to also previous proceedings of the same annual conference).
18. A.S. Arico, S. Srinivasan and V. Antonucci, DMFCs: From fundamental aspects to technology development, *Fuel Cells*, Vol. 1, pp. 133-161, 2001.