Syllabus
ChE-490/ChE-690: Analysis of Electrochemical Systems
Spring 2004
Ohio University
Department of Chemical Engineering

Instructor: Dr. Gerardine G. Botte
Office: 183 Stocker Center
Office Hours: 10:00-11:00 MWF (posted on office door) and by appointments (please use phone or e-mail to schedule appointments). I will see you almost any time I am in.
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Class: MW 4:10-6:00 pm, Stocker 194
Some Wednesday sessions (see tentative schedule) will be used for hands-on experience (graduate and undergraduate students) and computer sessions in modeling of electrochemical systems (graduate students). Stocker 194 or Stocker 044

Required texts: Electrochemical Engineering Principles. Geoffrey Prentice. Prentice-Hall, 1991, ISBN 0-13-249038-2

Recommended texts:
1. Electrochemical Systems. John S. Newman, Second Edition, 1991, ISBN 0-13-248758-6
2. Electrochemical Methods, Fundamentals and Applications. Allen J. Bard and Larry R. Faulkner, Wiley, 2001, ISBN 0-471-04372-9

Grading:
This is a double listed course. Expectations for graduate students are higher than for undergraduates (Ohio University policy). The grading distribution and the assignments have been designed to accommodate this.

Undergraduate Students		**Graduate Students**	
		Paper: 15%	GS Extra
Lab Reports: 25% Quizzes: 25% Course Project: 45% Class Participation: 5%	US	Lab Reports: 15% Quizzes: 25% Course Project: 40% Class Participation: 5%	US

Scale	
A	93-100
A^-	90-92
B^+	85-89
B	82-84
B^-	79-81
C+	76-78
C	73-75
C-	70-72
D+	66-69
D	63-65
D-	60-62
F	0-59

To qualify for class participation you should do one of the following: 1. Participate in at least 2 discussions in the class, 2. Solve at least two exercises during the class, 3. Participate in the workshop discussions.
Electro-chem-e-car competition incentive will be up to 4% extra-credit (for the course) depending on the results of the competition (see course project handout)

Course description and objectives:
Application of thermodynamics, transport phenomena, and reaction engineering to understand the performance of electrochemical systems and processes. Applications include electrolysis, batteries, and fuel cells.

After successfully completing this course, you will be able to:

1. Gain a better understanding of electrochemical systems
2. Understand the thermodynamics of electrochemical systems
3. Recognize electrode kinetics
4. Understand the transport mechanisms in electrochemical systems
5. Understand modeling procedures for electrochemical systems (graduate students)
6. Get familiar with typical electrochemical instrumentation
7. Gain "*hands-on*" experience with the *state-of-the-art* sources of energy such as batteries and fuel cells
8. Design, build, and test and electrochemical process

To fulfill the objectives of this course the class has been divided into *mentoring sessions, lab sessions, and workshops*.
The *mentoring sessions* will be used for presenting new concepts and problem solving techniques. The students are expected to read and understand all of the material in the sessions assigned in the textbooks, class notes, and handouts. The course material will be presented using active learning. The instructor will act as a mentor for the class. New concepts will be introduced using a presentation style. Students will have class time to solve problems (using the taught concepts) and ask questions (individually and by groups). After sometime, the complete solution of the problem will be discussed in class.
The *lab sessions* will be used to perform experiments that will allow you practicing the concepts presented during the mentoring sessions. You will perform the following experiments:

1. Lab I: Electrolysis
2. Lab II: Electroplating
3. Lab III: Fuel Cells

Graduate students will be required to attend computer lab sessions and special mentoring sessions to cover the modeling topics.
Workshops sessions will be used to discuss new research areas and special topics. The workshops will consist of a presentation followed by a demonstration session. During the demonstration students will get familiar with electrochemical characterization techniques and fabrication methods. Even though the material cover in the workshops is not graded is important that you participate in the discussions as they are part of class participation. It is suggested that you research on the topic before the class so that you can participate in the discussions and ask questions. Below is the list of the tentative workshops for the course:

1. *Lithium ion batteries*: In this workshop you will learn about the importance, uses, limitations, and research areas of lithium ion batteries. In addition, the students will go to the lab where four different working stations will be found: 1. electrodes fabrication, 2. battery assembly, 3. battery testing, and 4. battery performance.
2. *Plating and electrode characterization*: In this workshop you will learn about different plating techniques, advantages and disadvantages of plating, plating variables, and electrode characterization, etc. In addition, the students will go to the lab where seven different working stations will be found: 1. surface preparation, 2. electrode plating, 3. plating procedure schedule and data, 4. surface area, 5. adhesion, 6. morphology, 7. surface profile.
3. *Fuel Cells*: In this workshop you will learn about fuel cells, efficiency of fuel cells, types, advantages, disadvantages, fabrication of MEA, and design and economics of PEM fuel cells. To complete the discussion students will go to the lab where three different working stations will be found: 1. Fuel Cell performance, 2. PEM fuel cell parts, and 3. PEM economics in a spreadsheet.

4. *Hydrogen Economy*: In this workshop you will learn about what is hydrogen economy, advantages and limitations of hydrogen economy, hydrogen production methods, and state of the art on hydrogen production. To complete the discussion students will go to the lab where they will learn about the contributions of the EERL and OCRC to the hydrogen economy.
5. *Solid Oxide Fuel Cells*: In this workshop you will learn about solid oxide fuel cells and fuel processing technology. This workshop will take place in SOFCo-EFS (http://www.sofco-efs.com/)/, Alliance Ohio). The exact day of the workshop will be announced during the quarter, tentative dates include: 04/23, 04/30, or 05/07.

Class Notes: Class notes for the topics will be available at the course webpage. You are responsible for printing and bringing the notes to class.

Lab Reports: You will write a short report (maximum 5 pages) describing and discussing the findings observed during the experimental sessions. Your report should include the following sections:

1. Cover page
2. Data
3. Results and Discussion: discuss and answer the questions posted in the experiment handout
4. Calculations

Your behavior during the experiment will be observed and it will be considered in your report grade (lab attitude, 5 points). More details about lab grading are given in the lab grading sheet. All results and data must include uncertainties. Use propagation of error to determine uncertainties, for more details see “propagation of error #1” and “propagation of error #3” at http://webche.ent.ohiou.edu/che416/syll416w_2003.html

Quizzes: These quizzes will be closed notes, except for one piece of paper with the necessary equations. Any material needed will be provided during the test, or you will be told to bring it with you. The material you are responsible for under each format will be explained ahead of time. Basically each quiz will cover the content of each topic in the class (see tentative schedule for quizzes content and dates). You will have 30 minutes for the quiz.

Class project:

As your class project you will design, build, and test an electrochemical system. The electrochemical system that you will work on will be an electro-chem-e-car. Details about the project are given in the Final Project handout. It will be a team project. The team members will be selected by the instructor. There won’t be more than 5 members per team.

Class Paper (Graduate Students Only):

Graduate students are required to write a review paper for a topic that will be assigned by the instructor. The paper will be done by groups. The team members will be selected by the instructor. You must follow the structure of a review paper submitted for to a peer review journal. When doing the analysis of the papers you must be critical. You need to focus on importance of the research (or paper), limitations of the paper, identify the progress in science due to the contribution of the authors, suggestions for future work and improvements. The following structure is suggested for your paper:

1. Abstract
2. Introduction
3. Review of Papers: this is the section where you have to be critical (positive and negative aspects of the paper, importance of the paper, suggestions for future work. e.g., techniques used, materials tested, methodology employed, etc). See example given next, which was done for the analysis of the paper entitled: “Hydrogen production from coal water and electrons” by Coughlin and Farooque

Most of the studies available in the literature on electrolysis of coal/water slurries have been performed in batch systems (bulk electrolysis). None of the studies have been performed at pressures different than atmospheric. The thorough review presented next shows that it is necessary to perform additional studies for the design of a continuous coal/water electrolysis system; in addition, the studies must be performed using Ohio coal.

Coughlin and Farooque[4] reported the kinetics and thermodynamic feasibility of electrolyzing coal/water slurries. They did their experiments using Pt electrodes; however, they indicated that they did not observe significant differences in the electrochemical reaction when using graphite electrodes. The authors proposed that the electro-oxidation of coal/water slurries take place according to the reaction given in Eq. 1, while the reduction of hydrogen cations takes place at the cathode:

$$4H^+ + 4e^- \rightarrow 2H_2 \quad (2)$$

Therefore, the total reaction is given by:

$$C + 2H_2O \rightarrow CO_2 + 2H_2 \quad (3)$$

The theoretical potential required for the oxidation is 0.21 V, which represents, 11 W-h/H_2 mol. The theoretical energy consumed is much lower than for the electrolysis of water, 66 W-h/H_2 mol.

The authors[4] reported that the process produces practically pure streams of hydrogen at the cathode and carbon oxides at the anode (CO_2 with 3 to 7% CO). The authors noticed differences in the oxidation behavior of different coal samples: Montana Rosebud (char and coal), North Dakota lignite, Pittsburgh coal, and Illinois No. 6. Montana Rosebud was easier to oxidized and generated higher oxidation currents (faster reaction rate). The authors attributed the different behaviors of the coals to particle size (smaller the better), surface area (higher the better), and graphitic nature (effect of electronic conductivity, the higher the better).

The authors[4] noted a decrease on the oxidation rate with time. They claimed that it may be due to the formation of films on the coal surface (e.g., surfaces oxides, hydroxyl, carbonyl, or carboxyl groups) as reported by other researchers.[16-18] However, they did not perform any surface analyses. Some researchers[1] have reported that the presence of CO poisons platinum electrodes decreasing the reaction rate, therefore, it is possible that part of the behavior observed by Coughlin and Farooque[4] was due to CO poisoning, but this argument was not suggested or analyzed in their paper. They[4] also noticed that either by heating the coal up to 200 ^oC or by washing it with some organic solvent (e.g., acetone) the coal was reactivated (this procedure probably destroys the films on the surface of the coal).

Another important observation made by the authors[4]is that the ratio of the gases formed did not agree with the stoichiometry of the equations shown above (Eq. 3). Much less gases were collected at the anode than at the cathode. The reason could be due to a build up of the films on the surface of the carbon. It is our opinion that also, if CO_2 is formed in an acidic medium, another reason for not collecting gases according to the stoichiometry is that CO_2 is much more soluble in water than O_2, in addition, CO_2 can react with water and formed carbonic acid (H_2CO_3). This possibility was not analyzed by the authors.

4. Trends and Future work
5. References

Your paper should not be more than 10 pages (excluding cover page and references), double spaced with font size 12. Keep 1" margins (right, left, top, and bottom). Number all the pages. The paper topics will be:

1. Coal Fuel Cells
2. Electro-oxidation of ethanol
3. Alkaline Fuel Cells

Attendance: Students are expected to attend every class and lab session. If you miss an assignment or exam, contact me to schedule a makeup. There most be an honorable excuse for a makeup exam. If you know you *will* miss an exam, speak to me in advance to make arrangements. Refer to "Class Attendance" in the *Student Handbook* for the Ohio University policy on unanticipated absences.

Academic Conduct: Engineering is a profession, and ethical behavior is expected of professionals. You are expected to act in a professional manner in this course. Academic dishonesty is defined in the *Student Handbook* and will be dealt with according to the guidelines therein. Exchanging information on assignments or exams where such an exchange has been forbidden and plagiarism are violations of the standards set forth in this course and the *Student Handbook* in general. Appropriate penalties will be imposed, which could include failing the course and a referral to the Office of Judiciaries (refer to the *Student Handbook* for descriptions of unethical behavior and the potential penalties). Other potential violations include any action that deceives your professor or your classmates, and any action taken without due consideration of its possible harmful effect on others. I would not accept disrespect to me or to any of the students in the class. If you act in this way you will be asked to leave the classroom and you will loose any credits for the activity that takes place that day (including lab sessions and exams). You must have an appropriate conduct during the lab sessions.