A Multidisciplinary course on Fuel Cells: Their Science and Engineering

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Abstract

The Arizona State University Photovoltaic Testing Laboratory (ASU-PTL) is one of only three accredited labs in the world for the design qualification of photovoltaic modules per IEC and other standards. The ASU-PTL is currently positioning itself to carry out independent performance and design evaluation of fuel cell systems as well. In addition to this, curricula are being developed that provide students with both theoretical and practical knowledge of fuel cell systems and their operations. This paper presents the details about the first introductory, multidisciplinary course that was developed and taught at ASU for the first time in the spring of 2003. The course is at the advanced undergraduate and graduate level. The goal of the course is to provide graduates with up to date knowledge and understanding of fuel cells and their supporting systems.

In this course, students are exposed to concepts from electrochemistry, material science, chemical engineering, polymer science, fluid mechanics, thermodynamics, heat transfer, manufacturing and electrical and electronics engineering as they apply to fuel cell systems. This is a true multidisciplinary course. The interdisciplinary nature of the course necessitates a team-teaching approach, and faculty with backgrounds in electrochemistry, electrical engineering and mechanical engineering deliver portions of the course. The course includes a theoretical portion, and a comprehensive practical portion in which the students build a membrane electrode assembly (MEA) and assemble, test and characterize this assembly as a single stage proton exchange membrane fuel cell. The lab training also consists of making bipolar plates needed for the interconnection of the cells for normal operations.

The course was very well received and more work to refine the course is ongoing. Feedback from the students indicates a tremendous interest generated by the course, and several students intend to concentrate their graduate work in the fuel cell area.

Introduction

Today's cutting edge technologies are tomorrow's commercial technologies. Fuel cells have the potential to solve many of the dilemmas created by the energy demands of our society. With clean, quiet and efficient outputs, the potential importance of fuel cell technology cannot be overemphasized. However, the technology is yet to mature, there are many technical problems that need to be addressed. This has created a need for qualified scientists, engineers and technologists. An important goal of this course is to train engineering technology graduates, both at the undergraduate and graduate levels, who can contribute in an immediate and meaningful way to the advancement of fuel cell technology. To meet this goal, the course includes specific sections on theory, practice, oral presentations, report writing, and group projects. Consequently, coupled with the relevance of the technology, this course essentially meets all aspects of ABET criterion 1, outcomes a through k.

Fuel Cells – A Truly Interdisciplinary Subject

Teaching a fuel cell course is challenging because the field is truly interdisciplinary. For example, the load curve shown in Figure 1 illustrates that operating limitations are influenced by different phenomena depending on the operating point. Consequently, improvements to the operating envelope requires a team of experts from several different fields. To address this challenge, at ASU East it was decided to use a team-teaching approach with specialists in three different fields teaching portions of the course: Electrochemistry, Electronics Engineering Technology and Mechanical Engineering Technology.

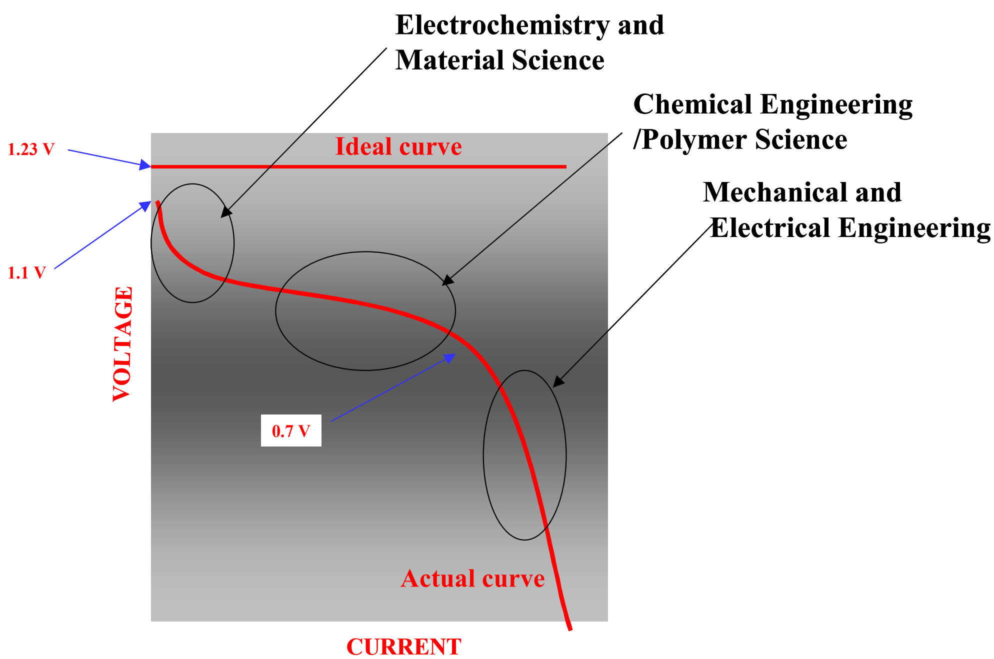

Figure 1: Interdisciplinary nature of Fuel Cell Technology

The interdisciplinary nature of this field is also represented by the student cross section in the course. Of the 21 students, 13 were graduate students in the College of Technology and Applied Sciences (CTAS), and the rest were seniors in CTAS. Among the graduate students, were 6 from Electronics Engineering Technology (EET), 6 from Mechanical Engineering Technology (MET), and one from Global Technology and Development. The undergraduates consisted of 6 EET and two MET students.

Course Structure

The course title is EET/MET 494/598: Fuel Cells: Their Applied Science & Engineering. It is a 3 credit, 4-part, 3-Instructor (the authors) course. The 4 parts are:

- Part 1 Fuel Cell fundamentals and operating principles
- Part 2 Power conditioning
- Part 3 Fuel processing and balance of plant
- Part 4 Laboratory practicals

Three instructors, with individual backgrounds in electrochemistry, electrical and electronics engineering and mechanical engineering, taught this course. Most of the classroom materials were presented as PowerPoint slides, and the students were provided access to these slides through a password restricted website. The major topics covered in the lecture portion of this course included:

- Introduction
- Thermodynamics and electrochemistry of fuel cells
- Operating characteristics of fuel cells
- Thermodynamic and electrochemical losses
- Electrical efficiency and heat rejection
- Effect of temperature and fuel cells
- Types of fuel cells and their construction materials
- Proton exchange membrane fuel cells
- Fuelling fuel cells including fuel processing and storage
- Compressors, turbines, ejectors, fans, blowers, and pumps

- Delivering fuel cell power (dc/dc, and dc/ac converters, power electronic devices, such as MOSFETs, and their characteristics)
- Bipolar plate design and manufacturing

Technical Level of the Course

In this course, students are taught fuel cell thermodynamics and electrochemistry, and the systems engineering principles necessary to be productive in the fuel cell field. As stated, a primary goal of the course is that the students, upon course completion, should be able to contribute in a meaningful manner to fuel cell research and development projects and initiatives. For example, the students are required to master practical calculations for fuel cell design and application. The calculation list includes:

- Calculation of high heating value (HHV) and low heating value (LHV) based on bond energies
- Calculation of ideal voltage and efficiency
- Calculation of temperature and pressure effects on voltage
- Calculation of minimum required flow rates of the reactants for stacks and individual cells
- Calculation of water production
- Calculation of practical efficiency and heat rejection, and
- Calculation of catalyst and membrane costs

Throughout the course, assignments are developed based on the application of fundamental theoretical and practical aspects of the field. An example assignment is shown below in Figure 2.

Assignment 1

A Report on:

Proton Exchange Membrane Fuel Cells

- **Topics to be covered**
  - **INTRODUCTION**

  - **PEM FUEL CELLS**
  - **Hydrogen sources for PEM fuel cells**
  - **Hydrogen storage**
  - **Construction materials: membrane type, catalysts used, bipolar type, coolant etc**
  - **Efficiency: Ideal and practical**
  - **Typical performance: Discuss the temperature and pressure effects**
  - **Lifetime**
  - **Manufacturers**
  - **Merits and demerits: as compared to other fuel cell technologies**
  - **Applications (residential, automobile, military and portable)**
  - **Commercialization issues**

  - **INTERNET SURVEY: DEMONSTRATION/RESEARCH PROJECTS AND UNIVERSITY COURSES**
  - **Identify demonstration Projects by Companies: Any fuel cell technology**
  - **Identify research projects by the US Universities: Any fuel cell technology**
  - **Idetify the courses offered in the US Universities: Any fuel cell technology**
  - **Identify the testing and certification agencies/laboratories in the US**
  - **Identify the job opportunities in the field of fuel cells**

  - **CONCLUSIONS**

Figure 2: Example Assignment

Laboratory Experiments

The objective of this practical is to fabricate and test a proton exchange membrane fuel cell membrane assembly and to operate a single cell proton exchange membrane (PEM) fuel cell. This practical is designed to give the students an understanding of the individual components of a PEM fuel cell, the process of manufacturing a proton exchange membrane electrode assembly, and the operating principals and conditions of a PEM fuel cell. Students were assigned to work in teams of 3 or 4.

The first part of the practical was to construct a membrane electrode assembly (MEA) using the equipment supplied by the Fuel Cell Laboratory. The second portion of the practical was to assemble the membrane electrode assembly into the fuel cell test fixture. Finally, the third portion of the practical was to mount the fuel cell test fixture onto the fuel cell test station, collect the voltage and current data, and plot the load curve at different temperatures (25°C, 40°C, 60°C, 80°C). Students were given handouts of every aspect of the laboratory experiment and were constantly supervised. Figures 3 and 4 show the loading of the MEA and the fuel cell station, followed by typical readings taken by a graduate student. Shown below are a sample set of readings (Table 1). Figure 5 shows the voltage current curve at 60°C. Students were expected to report and critically evaluate the results of these experiments. For example, the results on Figure 6 show that current density increased with increasing temperature, a result that is consistent with expected fuel cell operation. Each student was required to submit a professional final report on the laboratory experiments and the lessons learned.

Figure 3: MEA Going into Hot Press.

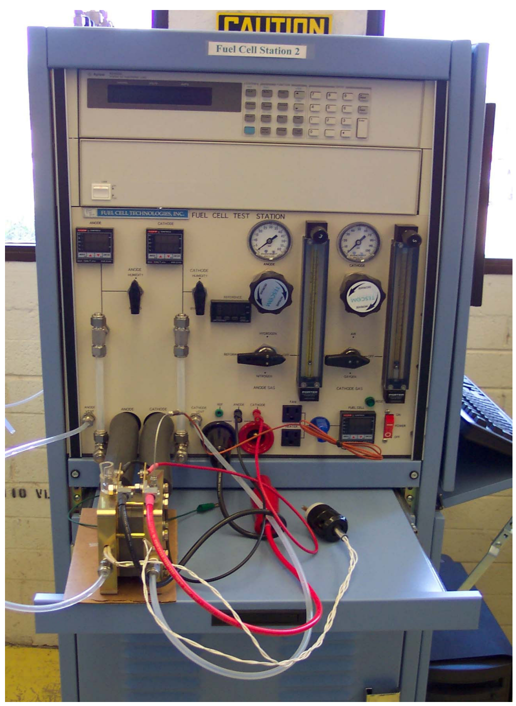

Figure 4: Fuel Cell Test Station.

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Cell Voltage, V	Cell Current, A
0.915	0.000
0.700	0.017
0.600	0.114
0.500	0.258
0.400	0.438
0.300	0.616
0.200	0.732
0.100	0.771

Date and Time	5/1/2003, 12:00 Noon
Cell Temperature	80^{o}C
Humidifier Temperature (H_2/O_2)	90^{o}C/90^{o}C
Pressure (H_2/O_2)	Atmosphere
Flow Rates (H_2/O_2)	30 CCM/60 CCM
Open Circuit Voltage	0.925 V

Table 1: V-I Data and Test conditions at 80^{o}C

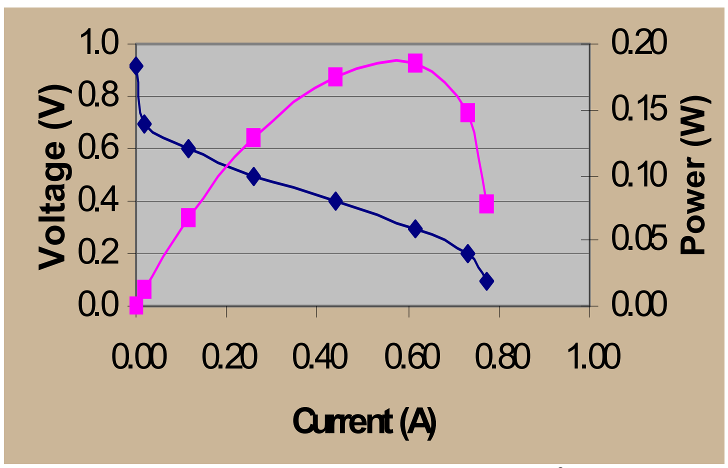

Figure 5: Voltage-Current Curve at 60^{o}C

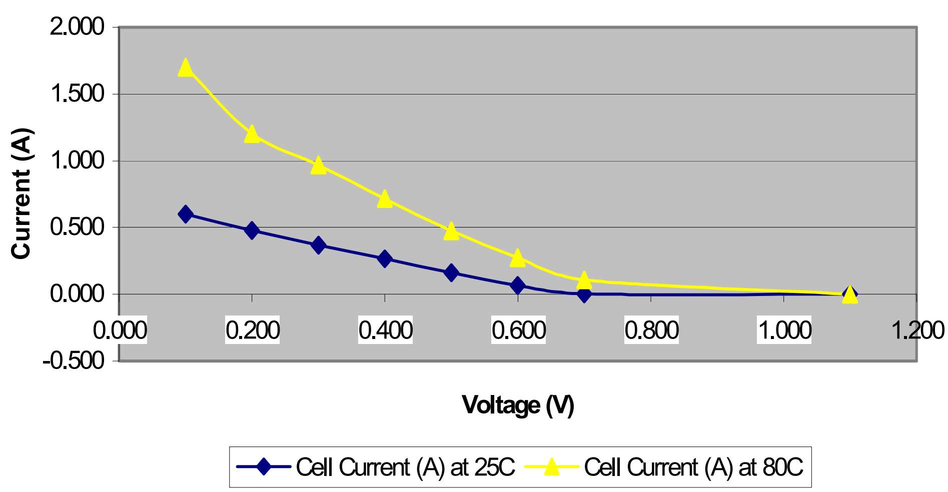

Figure 6: Increase of Current Density with increase in Temperature.

Student Presentations

In order to develop technical writing and presentation skills, as well as teamwork, the class was required to study, write up and present results of assigned research topics. This portion of the class accounted for 10% of the course grade. The students were divided into groups, typically of three students, with the groups including students with both mechanical and electrical backgrounds. Examples of topics include the following:

- Fuel cell based back-up power systems
- Fuel cell based residential systems
- Fuel cell based combined heating and power (CHP)
- Fuel cell based hybrid systems
- Solar-hydrogen-fuel cell systems
- Fuel cells for portable applications
- Fabrication of bipolar plates

In addition to valuable information on fuel cell technology, it was found that the pressure of a formal presentation in front of their peers was very motivating to the students. The quality of the presentations and associated research papers were very high. The primary criticism was that most groups went over the established time limit of 20 minutes for their presentations.

Student Evaluation

The success of the course was reflected by the student evaluation ratings. The course instructor evaluation by the undergrad students was 4.76/5, which is very much above the department average. The course rating was 4.69, which again is much above the average. Similar excellent ratings were also given by the graduate students (4.76/5 and 4.51/5, respectively). The only other concern expressed by a few was that there was too much material for a 3 credit one semester long course.

Conclusion

The idea of using an interdisciplinary team to teach the topic of fuel cells has been very successful at ASU. The experience has been very rewarding for both students and faculty, and is a catalyst that is leading to substantial increases in research efforts in the fuel cell area. For example, several graduate students have decided to pursue research in the area. In addition, the course has generated much interest in alternate energy technologies, leading to increased population in existing courses in green energy and photovoltaics, as well as the creation of new courses in areas such as wind energy. In addition, two of the students in the class obtained jobs in the fuel cell field after completion of the course, indicating industry support and recognition of the course quality.

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