School of Engineering and Technology, IUPUI
Multidisciplinary Undergraduate Research Institute (MURI)

MURI Mentors Project Application Form

For Fall 2005

To be completed by a Mentor Faculty Member or Researcher from the School of Engineering and Technology.
To fill in this form place your cursor in the form field and type. Tab from field to field.

Date: July 18, 2005

Name of Proposer: Andrew Hsu

Title of Proposer: Professor

Department of Proposer: ME

Proposed Project Title: Research in Fuel Cell Technology

Approximate Duration: Fall 2005 semester

Number of Students Requested: 3

Disciplines or Majors Involved (at least two disciplines): ME, ECE, Chemistry

Support Needed from MURI for Supplies and Equipment Usage ($2,000 limit per team): $2000

Project proposal with sections for the following information (please attach or cut and paste into this form):

> *1) Objectives, 2) Research Methodology, 3) Team Organization, 4) Expected Outcomes, 5) Benefits, 6) Time-Table, 7) Justification of Budget for Equipment and Supplies, 7) Short Resume. No more than five pages, excluding resume.*

1) Objectives

The undergraduate fuel cell research lab aims at exploring and promoting multi-disciplinary research and development options for undergraduate students. The mission is to foster the development of fuel cell technologies and their utilization in industrial, commercial, and transportation applications.

The proposed project for this summer is to test a fabrication and testing procedure for formic acid fuel cells. The long term objective is to explore renewable fuel sources for fuel cells and develop truly green fuel cell technologies.

2) Research Methodology

A passive (no fuel pump) formic acid fuel cell system was very recently introduced to be used as a power supply to cellular phones that require 1~2 W power. DMFC has also been studied and demonstrated in passive designs to target such a low power-consumption device. The reported performance data are briefly compared in Table 1.

TABLE 1. Passive DFAFC and DMFC performance reported

	Passive DFAFC	Passive DMFC
Membrane	Nafion 112 or 117	Nafion 112
Active cell area	25 cm²	36 cm²
Catalyst (anode)	Not specified	6.4 mg/cm² (Pt/Ru, unsupported)
Catalyst (cathode)	Not specified	3.9 mg/cm² (Pt, unsupported)
Fuel	10 M formic acid, 20°C	4 M methanol, 20°C
Key performance data	0.59 V at 0.1 A/cm² (59 mW/cm²) 0.32 V at 0.4 A/cm² (128 mW/cm²)	0.32 V at 0.035 A/cm² (11 mW/cm²)

Though there are wide variations in operating conditions and MEA specifications, the reported power density of passive DFAFC is clearly higher than that of passive DMFC by an order of magnitude. Such a higher performance seems to be mostly due to the low fuel crossover of formic acid that allows a high concentration fuel in the fuel reservoir. An active DMFC running at a constant fuel flow rate does not usually allow a methanol concentration larger than 1 M, due to significant drop of performance caused by methanol crossover. On the other hand, passive DMFCs have shown an optimum methanol concentration near 4 M , which is higher than in active systems because without pumps a higher methanol concentration is necessary to create concentration gradients for sufficient diffusion rates. The passive DFAFC was reported to be able to run with even much higher formic acid concentrations of 10~15 M. The capability of running at higher fuel concentrations is crucial for the passive system design because it minimizes fuel storage space and weight and it keeps higher energy densities.

Based on the performance data in Table 1, DFAFC appears to be superior to DMFC for a passive system design. It does not answer, however, whether a 20 W passive DFAFC system would be possibly made in the very near future. A low-power device such as cellular phones is quite feasible with the current DFAFC performance. To generate 1 W from a passive DFAFC with good performance, one would need only 10 cm² active area. Without a high voltage requirement, four cells of 2×2 in² can meet the power demand. A 2×2 in² single cell module can be made with a formic acid fuel cartridge. Each module should have anode and cathode connecting wires, and four modules can be simply packed to make a 1 W power generator. This is in fact what was shown in the recent passive DFAFC development report. Though an optimized compact design will need many years of development, a basic design of passive DFAFC is possible for such a low-power application. The design of a passive DFAFC for 20 W at 12 V must be very different. It requires stacking technologies. To supply 12 VDC electricity, a minimum of about 20 cells are practically needed to meet the voltage requirement, based on the current performance data. The single cell modular design approach for low-power devices (1~2 W) would not work in this case. A stack should provide uniform fuel and air delivery to every cell at sufficient flow rates to produce the required power.

Since the fuel transport mechanism in passive systems is diffusion driven by concentration gradients, mass transfer is much slower than in active systems where the fuel transport is driven mostly by forced convection from pressure gradients (pumps). Fuel concentration in a reservoir should decrease gradually as formic acid is consumed for fuel cell reactions. Not all fuels stored initially in a reservoir will be actually utilized for power generation, because the performance will drop significantly at some point as fuel concentration becomes too low. There must be a cut-off time (t_{cut}) when a time-dependent overall (cumulative) fuel utilization remains almost unchanged (Fig. 1). The fuel reservoir or fuel cartridge needs to be replaced at that time. No studies have ever been tried regarding a cut-off time in passive fuel cell systems. A lot of this study must be a part of Phase II, but at least some initial studies will be needed to see if and how this definition of cut-off time (depicted in Fig. 1) is observed during a passive DFAFC operation. We will experimentally and theoretically investigate this issue. If such a behavior predicted in Fig. 1 is observed, an optimum cut-off time must be decided to ensure the generation of 20 W power for 72 hours at a given fuel amount and initial concentration.

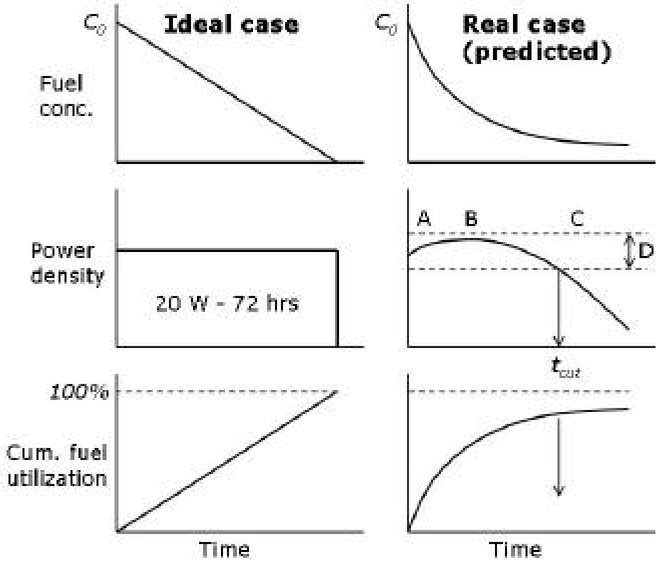

Fig. 1. Predicted change of fuel concentration in a reservoir and power density at a constant voltage or current operation. The prediction assumes an initially low performance region due to fuel crossover at high concentrations (A) and then a stable performance region (B) until the slow mass transfer at low concentrations causes a significant drop of performance (C). A cut-off time is defined based on a range of acceptable performance (D).

The design of fuel reservoir and air-breathing cathode is also a big challenge for a passive DFAFC stack. Uniform fuel distribution is not guaranteed as the number of cells becomes large. A passive fuel cell stack can be more serious on the fuel distribution issue than an active fuel cell stack, because diffusion by concentration gradients is more difficult to control than pressure-driven flow rates. Concentration gradients will certainly exist between cells, and they will cause a significant difference in fuel delivery to cells. Some external factors such as gravity force and temperature gradient will affect the fuel concentration gradients and those noise factors should be accounted for in the design. The fuel reservoir must be replaceable after a minimum 72-hour use. A fuel cartridge having enough formic acid for 1440 Wh (20 W for 72 hrs) must be easily attachable and detachable during power generation. The size and capacity of a single replaceable cartridge are important in the overall weight of the system. The amount of air required is also important. Air-breathing fuel cell stacks can be easily subject to shortage of oxygen in the cathode which will drop performance regardless of how well the fuel electrode (anode) performs. In passive fuel cells, air can be delivered from surroundings only by natural convection and diffusion which provide much lower flow rates than forced convection from pumps.

Heat management is another issue that is not serious in single cells but significant in all types of fuel cell stacks. Fuel cell is a device that converts chemical energy into electrical and thermal energies. The amount of thermal energy produced depends on current load, activation overpotentials, ohmic resistance, and number of cells. Heat accumulation inside fuel cell stacks depends on those and more other factors such as stack size, heat dissipation rates to surroundings, and so on. Unless a fuel cell stack runs at a very low current load, the rate of heat generation is usually larger than the rate of heat loss or cooling. This causes an increased fuel cell temperature above a standard operating condition. As Nafion-based fuel cells have to run below 100°C for the need of membrane humidification, it is important to design a system that remains below 90°C during continuous operation. In an active system, the rate of heat generation can be balanced by the rate of cooling with increased air flow rates in the cathode. The air cooling is not possible in the passive design concept. A passive system is therefore more vulnerable to an unexpected temperature rise than an active system.

3) Team Organization

A multidisciplinary team will be formulated this coming Fall Semester when the students returns. Mr. Alan Benedict, an ME student, will lead the student team. Two more students from ME, ECE, or Chemistry Departments will be hired.

4) Expected Outcomes

1. The student will gain hands on experience in fabricating and testing a formic acid fuel cell.
2. A procedure will be established for the fabrication and testing which can be followed during the next fall research.

5) Benefits

There are three main benefits:

1. Students get research experience in a high-tech area.
2. The research results will feed into current and future funded research.
3. The project will help the development of a new course on fuel cell technology to be taught the first time at IUPUI this coming fall semester.

6) Time-Table

The proposed period for this activities is 12 months. The current period only covers this summer The described tasks will be carried out on the following schedule.

Task	Description	1rst quarter	2nd quarter	3rd quarter	4th quarter
2.1	Fabrication of MEAs for single cells and tests				

2.2	Tests of single cells in a passive system				
4	Identify and testing other similar fuels for green applications.				

7) Justification of Budget for Equipment and Supplies

Fabrication of Membrane Electrode Assemblies (MEAs)
Budget requested: Polymer membrane $500
Carbon Sheets $500
Catalytic Ink $800
Formic Acid $200

8) Short Resume

Andrew T. Hsu, Ph.D.

Professor of Mechanical Engineering
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PROFESSIONAL PREPARATION

Post-doctoral Fellow, School of Aerospace Engineering, Georgia Institute of Technology, January 1986- August 1987
Ph.D. in Aerospace Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1986
M.S. in Aerospace Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1982
M.S. in Hydraulic Machinery, Tsinghua University, Beijing, China, 1981
B.S. in Hydraulic Machinery, North China Institute of Hydraulic and Electric Power Engineering, 1978

APPOINTMENTS

Professor of Mechanical Engineering, Indiana University - Purdue University Indianapolis, 2003-Present

Associate Professor of Mechanical Engineering, Indiana University - Purdue University Indianapolis, 1999-2003

Associate Professor of Mechanical Engineering, University of Miami, Florida, 1997-1999
Staff Research Scientist, Rolls-Royce Corporation, Indianapolis, Indiana, 1995-1997

Supervisor, Computational Physics Section, Sverdrup Technology, Inc., NASA Lewis Research Center, 1990-1995

Senior Research Engineer, Sverdrup Technology, Inc., NASA Lewis Research Center, 1987-1990

NASA-ASEE Summer Faculty, NASA Lewis Research Center, May-August, 1998

SELECTED PUBLICATIONS

Project-related

1. Sun, C., and **Hsu, A.T.,** (2004) “Multi-level lattice Boltzmann model on square lattice for compressible flows“ *Computers and Fluids*, v 33, n 10, p 1363-1385
2. Guo, Y. and **Hsu, A.T.** (2004) “Extension of CE/SE method to 2D viscous flows” *Computers and Fluids*, v 33, n 10, p 1349-1361
3. Sun, C., and **Hsu, A.T**., (2003). “Three-dimensional lattice Boltzmann model for compressible flows,” *Physical Review E*, Vol. 68, No. 1, p. 2

4. ***Hsu*, A.T.** and Yang**, T., "Molecular Dynamics Simulation of Nano Scale Channel Flows", ASME First International Conference on Nanoscale/Molecular Mechanics, Hawaii, May 12-17, 2002.*
5. ***Hsu*, A.T.,** Yang**. T., Sun, C., and Lopez. I, "A Lattice Boltzmann Method for Turbomachinery Simulations," AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Indianapolis, IN. July 7 - 10, 2002.*

Please submit applications to MURI Scholars Program, IUPUI Center for Research and Learning, 755 W. Michigan Street, UL 1140, Indianapolis, Indiana 46202, Tel: 317-278-1028, Fax: 317-278-3602.