THE SECOND WORKSHOP ON RECENT ADVANCES IN FUEL CELLS

sponsored by

and organized by

University of Ontario Institute of Technology
Oshawa, ON, Canada
September 26, 2011
PREFACE

The research and development on fuel cell science and technology have advanced significantly in the last decade. Various research groups have made a significant progress on the development of different types of fuel cells which can effectively and efficiently be used in several sectors, ranging from portable to stationary applications. Federal and provincial governments have also emphasized the importance of using fuel cell systems for power production in Canada and have initiated some incentive plans to promote their use. This workshop aims to bring together researchers, scientists, engineers, policy makers, and students from academia, industry, and government sectors to provide an opportunity for exchange the knowledge, share the experience, and foster relationships that will certainly strengthen the works done in these sectors.

We have invited 11 distinguished speakers from industry, academia, and national laboratories in North America. A wide range of topics are covered by their talks, including experiments, modelling, materials, manufacturing, and future strategies for fuel cell science and technologies. Each talk is followed by a Q&A period. The program offers a unique set of technical activities, such as invited talks, panel discussion sessions, a poster session and a group information session.

I would first like to thank Mitacs for sponsoring this event through their Mitacs Elevate program and Mitacs Networking events fund. Second, I would like to acknowledge the support provided by the University of Ontario Institute of Technology (UOIT). Third, I would like to appreciate the contributions made by the invited speakers, group session speakers, poster presenters and session chairs. Last but not least, I would like to register my sincere appreciation to the organizing committee members whose their efforts have made this event possible.

We wish you all a fruitful meeting and a pleasant stay in Oshawa.

Dr. Ibrahim Dincer
Workshop Chairman

Organizing Committee Members (in alphabetical order):
Ehsan Baniasadi, UOIT
C. Ozgur Colpan, Ryerson University
Ibrahim Dincer (Chairman), UOIT
Siamak Farhad, University of Waterloo
Halil Hamut, UOIT
Aydin Nabovati, University of Toronto
Ahmet Ozbilen, UOIT
About Mitacs Elevate

Mitacs has played a leadership role in linking businesses, government agencies, and not-for-profit organizations with over 50 Canadian universities to develop cutting-edge tools to support the growth of Canadian knowledge-based economy since 1999. Their cutting-edge programs focus on developing and attracting a new generation of Canadian researchers and entrepreneurs through skills training & entrepreneur workshops, technical training events, graduate and post-doctoral internships, and outreach activities.

Mitacs Elevate started as a pilot program for postdoctoral fellows (PDFs) in Ontario in 2010. The program recently was introduced in the province of British Columbia as well. Mitacs Elevate provides a foundation of cutting-edge research, business, entrepreneurship and scientific management skills to newly-minted PhDs. It also gives companies access to a highly qualified uniquely trained pool of talent. Through Mitacs Elevate, new PhDs create and lead a major industrial research project while establishing vital connections within the local business community.

Elevate PDFs take part in a customized training program to further develop their professional development skills, which includes courses in project management, communication and networking skills, and scientific management trainings. They also have the opportunity to investigate other areas of interest such as commercialization and/or entrepreneurship. Elevate PDFs who do not currently have a research collaboration with an industrial partner are involved in developing an individualized program to engage industry with support from Mitacs staff. All the PDFs are also given the opportunity to organize seminars and workshops related to their field of research. These events provide PDFs with an opportunity to showcase their research, and can also be leveraged towards extending their current professional network and building new industrial relations.

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Workshop Program — Room SSB116ab

07:30-09:00 Registration and Breakfast (8:00-9:00)
09:00-09:30 Opening Speeches
   - Ibrahim Dincer, Chair, UOIT
   - Tim McTiernan, President, UOIT
   - Richard Marceau, Provost, UOIT
   - Melinda Benn, Mitacs Elevate

Session-1: Low Temperature Fuel Cells -I  Chair: Greg F. Naterer
09:30-10:00 1.1 “PEM Fuel Cells: Progresses, Challenges, Status and Future Prospects”, X. Li
10:00-10:30 1.2 “What Makes Nafion Special? Mechanical and Transport Properties of Polymer Electrolytes for Fuel Cells”, J. B. Benziger
10:30-11:00 Coffee Break

Session-2: Low Temperature Fuel Cells -II  Chair: Tony Mazza
11:00-11:30 2.1 “Recent Advances in Microfluidic Fuel Cells”, D. Sinton
11:30-12:15 Panel Discussion Session: “Opportunities and Challenges with Low Temperature Fuel Cells”, J.B. Benziger, X. Li, D. Sinton
12:15-13:35 Lunch Break and Poster Session

Session-3: Group Information Session  Chair: Murat Aydin
13:55-14:15 3.2 “A Re-Examination of the Aluminum-Air Hybrid Vehicle”, J. Stannard
14:15-14:35 3.3 “Canadian Activities in Hydrogen and Fuel Cell Commercialization”, T. Kimmel
14:35-14:55 3.4 “NSERC H2CAN Network and Hydrogen Safety”, A.V. Tchouvelev
15:15-15:45 Coffee Break

Session-4: High Temperature Fuel Cells  Chair: Andrei V. Tchouvelev
15:45-16:15 4.1 “Electrodes for Direct Utilization of Fossil Fuels in SOFC”, R.J. Gorte
16:15-16:45 4.2 “Direct Ammonia Fuel Cells and Renewable Ammonia for Clean Electricity and Heat”, A. McFarlan
16:45-17:15 4.3 “Perovskite Anodes for SOFCs”, J.B. Giorgi
17:15-18:00 Panel Discussion Session: “Opportunities and Challenges with High Temperature Fuel Cells”, J. Gorte, A. McFarlan, J. B. Giorgi
18:00-18:15 Closing Remarks and Awards Ceremony
18:15-20:30 Closing Reception and Dinner
1.1 PEM Fuel Cells: Progresses, Challenges, Status and Future Prospects

Xianguo Li
Mechanical and Mechatronics Engineering Department, University of Waterloo

Abstract
Polymer electrolyte membrane (PEM) fuel cell has been aggressively developed worldwide as a clean power source for portable, mobile and stationary cogeneration applications. Significant progresses have been made in terms of cost reduction, improvement in the durability and reliability, as well as in the performance and power density. For automotive applications, cold start capability has been demonstrated in real fuel cell vehicles. However, significant technical challenges remain to be resolved before widespread commercialization of PEM fuel cell technology. In this presentation, the progresses achieved will be reviewed in terms of the technology development and fundamental understanding, outstanding technical barriers to commercial applications of PEM fuel cells will be described, current efforts/understanding and possible resolutions to the technical challenges will be outlined. In addition, endeavor will be made to elucidate future prospects and research directions of PEM fuel cells.

Biographical Sketch
Xianguo Li was born in the City of Linhai, Zhejiang Province, China. He received his Bachelor of Engineering degree in 1982 from Tianjin University, China, in the field of thermal engineering. In 1984 he went to Northwestern University, Evanston, Illinois, U.S.A. for his graduate studies, and completed Master of Science program in June 1986, and Ph. D. program in June 1989. Afterwards, he joined the University of Waterloo as a postdoctoral fellow, and was later appointed Research Assistant Professor. In January 1992, he joined the Department of Mechanical Engineering, University of Victoria, Victoria, B.C., Canada, as an Assistant Professor, and was promoted to the rank of Associate Professor with tenure on July 1, 1994. On September 1, 1997, he rejoined the University of Waterloo as a tenured associate professor, and was promoted to the rank of full professor on July 1, 2000.

Dr. Li is a member of various international and Canadian professional organizations (such as AIAA, ILASS, ASME, and CSME) and served on ASME Emerging Energy Technology Committee. He was a member of New York Academy of Sciences from 1996-1999. He has also served on the organizing committee for the symposium on emerging energy technology as part of Energy Week Conference and Exhibition, co-sponsored by ASME and API, was the chair of the organizing committee for the 1996 Spring Technical Meeting of The Combustion Institute, Canadian Section, and co-chair of the Symposium on Thermal and Fluids Engineering, Canadian Society for Mechanical Engineering Forum 1998. Dr. Li served on the executive committee and as the vice president of the Engineering Institute of Canada, Vancouver Island Branch, in 1996-97; and the chair of the ASME Emerging Energy Technology Committee, and the chair of the organizing committee for the Symposium on Combustion and Alternative Energy Technologies (CAET), as part of ASME Energy-sources Technology Conference and Exhibition (ETCE) held in Houston, Texas, February 5-7, 2001. Dr. Li has also served on the organizing committee or international scientific and advisory committee for numerous national and international conferences.

Poster A Two-Dimensional Mathematical Model For Molten Carbonate Fuel Cells

Masoud Y. Ramandi, Ibrahim Dincer and Peter Berg
Faculty of Engineering and Applied Science, University of Ontario Institute of Technology

Abstract
It is theoretically and experimentally perceived that a non-uniform distribution of temperature, reaction rate and current density throughout the molten carbonate fuel cells (MCFCs) can deteriorate the cell performance. These three parameters are strongly coupled through the Butler-Volmer equation. In addition, it is known that in the industrial sized fuel cells, the temperature difference can be up to hundred degrees at maximum load which can cause corrosion and electrolyte evaporation and some other disadvantages. Therefore, there is an obvious need to develop a comprehensive mathematical model that can be employed to numerically simulate the fuel cell operation and find the parameters distribution. Thus, a two-dimensional mathematical model is developed to describe the transport phenomena and electrochemical processes in MCFCs. The governing equations are discretized, using the finite volume-based commercial software, ANSYS FLUENT 12.0.1. However, MCFC modelling is not yet supported by ANSYS FLUENT. Hence, the programming language C is utilized to develop an in-house code which is successfully compiled in the software environment. This procedure appends an MCFC specific module to the software which can be used for any MCFC. The logic of the model and program is described in this poster.
In this poster are presented selected fuel cell systems with single, co- and tri-generation using various technologies, as proton exchange membrane, solid oxide electrolyte with oxygen ions of protons transport. The fuels considered are hydrogen, methane, ammonia and urea. Using co-generation increase the system efficiency and fuel utilization factor up to over 80%. Ammonia shows the additional feature, with respect to other fuels, to produce a refrigeration effect by slight expansion which facilitates the implementation of a tri-generation system for power, heat and cooling (e.g., air conditioning) production. System integration is important for increased effectiveness. An example is included with a methane fuelled solid oxide fuel cell integrated with a gas turbine and a heat exchanger network for internal heat recovery from hot gases. For detailed reference the poster includes a list of publications of the authors on fuel cell systems topic.

**Biographical Sketch**

Jay Benziger is a professor of Chemical Engineering at Princeton University. He was educated in Mathematics, Chemistry and Chemical Engineering at Carleton College, Columbia University and Stanford University. He is an expert in chemical reaction engineering and chemical process technology. Professor Benziger’s group has developed novel reactor configurations for Polymer Electrolyte Membrane Fuel Cells that provided the physical basis for water management and controlling the dynamic behavior of PEM fuel cells. Professor Benziger’s group has also elucidated the coupling of mechanical properties and water and ion transport processes in polymer electrolytes. In collaboration with Steve Forrest his group has developed new reactor designs for continuous processing of organic thin film deposition for OLEDs and solar cells with Organic Vapor Phase Jet Deposition. Professor Benziger has led the development of systems that purified one thousand tons of organic liquid scintillator to contain less than 1 radon atom per ton for the Borexino Solar Neutrino experiment that has permitted the successful measurement of the 7Be neutrino flux. Professor Benziger co-authored over 200 papers in refereed journals. He has received the Exxon Award in Solid State Chemistry from the Inorganic Chemistry Division of the American Chemical Society, and the Purdy Award from the American Ceramic Society.

Professor Benziger teaches courses in Catalytic Chemistry, Energy Technology, Engineering Ethics and Social Responsibility, Chemical Reaction Engineering and Chemical Engineering Laboratory. He has served as the Faculty adviser overseeing the undergraduate program in Chemical Engineering and also coordinates a summer research program for undergraduates in the Princeton Institute for Science and Technology of Materials. Professor Benziger is active in the American Chemical Society, the American Institute of Chemical Engineers, and the Materials Research Society. He currently serves as the Chairman of the Central Jersey Section of the AICHE.
2.1 Recent Advances in Microfluidic Fuel Cells
David Sinton
Mechanical and Industrial Engineering, University of Toronto

Abstract

This presentation will provide an overview of the microfluidic fuel cell concept and a focus on our recent developments in this area. This work has involved detailed studies of the transport phenomena, and the development and testing of new microfluidic fuel cell architectures that exploit these phenomena to concurrently improve power density and fuel utilization. Examples include planar and 3-dimensional microfluidic fuel cells, microfluidic fuel cells with flow-through porous electrodes, and microfluidic fuel cell stacks. In closing, some future opportunities for this technology will be discussed.

Biographical Sketch

David Sinton is an Associate Professor in the Department of Mechanical & Industrial Engineering at the University of Toronto. Prior to joining the University of Toronto, Dr. Sinton was an Associate Professor and Canada Research Chair at the University of Victoria, Victoria, British Columbia (2003-2011). He was a visiting Associate Professor at Cornell University Sibley School of Mechanical and Aerospace Engineering (2009-2010), and continues as an Adjunct Professor at Cornell. He received a BASc from University of Toronto (1998), MEng from McGill University (2000) and PhD from University of Toronto (2003).

Dr. Sinton’s research interests are in fluidics and energy. This research involves the study and application of small scale fluid mechanics (microfluidics, nanofluidics, and optofluidics) for use in energy systems and analysis. He received the 2006 Canadian Society of Mechanical Engineering I. W. Smith Award, the 2006 Douglas R. Colton Award from CMC Microsystems, the 2007 Award for Teaching Excellence from the University of Victoria Faculty of Engineering, and the 2008 Early Career Achievement Award from the University of Toronto Faculty of Applied Science and Engineering.

Poster Energy, exergy and economic analysis of an ammonia based solid oxide fuel cell system for vehicular applications
# 13
Ehsan Baniasadi, Ibrahim Dincer and Greg F. Naterer
Faculty of Engineering and Applied Science, University of Ontario Institute of Technology

Abstract

This research examines an ammonia-fed solid oxide fuel cell based on a proton conducting electrolyte (SOFC-H+), including heat recovery. Both energetic and exergetic performance of the combined heat and power (CHP) system for vehicular applications is evaluated. The performance of the SOFC system is studied for a range of the cell’s current densities and fuel utilization ratios. The relations between capital costs and thermodynamic losses for the system components are investigated. A parametric study is also conducted to investigate the system performance and costs of the components, depending on the operating temperature, exhaust temperature, and fuel utilization ratio. For the heat recovery option, the system exergy efficiency is calculated to be 60–90% depending on the current density, whereas the energy efficiency varies between 40-60%. The largest exergy destruction occurs in the SOFC stack, micro turbine, and first heat exchanger. The entropy generation rate in the CHP system shows a 25% decrease for every 100 oC increase in the average operating temperature. The ratio of exergy consumption to capital cost is found to be strongly dependent on the current density and stack temperature, but less dependent on the fuel utilization ratio.
Hydrodynamic Characterization of Gas Diffusion Layer in Polymer Electrolyte Membrane Fuel Cells
Aydin Nabovati and Cristina H. Amon
Department of Mechanical & Industrial Engineering, University of Toronto

Abstract
Hydrogen-based power systems, specifically fuel cells, have attracted a lot of attention in the last decade due to their low CO2 emission, high efficiency, and versatility. Among different types of fuel cells, polymer electrolyte membrane (PEM) fuel cells, which typically have efficiencies over 50%, are a promising option for either the transportation sector or stationary power production.

In this work, we focus on characterization of the carbon fibre substrate paper (CFP) part of the gas diffusion layer (GDL). Computed tomography imaging technique will be used to digitally reconstruct the detailed structure of different types of CFP. For each CFP type, samples with different porosities will be examined. The method that we will use to simulate fluid flow in our CFP geometries is the lattice Boltzmann method (LBM). The LBM is capable of accurately capturing the physics of fluid flow in complex geometries, such as those found in CFP, with no need for assumptions. The objective of these numerical simulations is to rigorously investigate the hydrodynamic performance of different CFP samples. The outcome of this project will be used to characterize the different types of CFPs that are currently used in the manufacturing of fuel cell stacks in Canadian fuel cell industries. The obtained knowledge will help the industries to optimize the CFP structure, select the most appropriate CFP type, and increase the reliability of their manufactured fuel cell stacks.

An Overview of Fuel Cell Activities in the Sustainable Energy Systems Research Group at UOIT
Ibrahim Dincer
Faculty of Engineering and Applied Science, University of Ontario Institute of Techno

Abstract
In this talk, an overview of what Dr. Dincer's group has been doing on fuel cells at micro- and macro-levels is presented. These works include various types of fuel cells, such as SOFCs, PEMFC, DMFCs, MCFCs, and ammonia and urea fuel cells. Various aspects of these, from electrochemistry to exergoeconomics, are studied and their performances are evaluated through energy and exergy efficiencies as well as some additional performance rating criteria. In addition, system integration and multi generation options for numerous applications are two key topics and are considered and studied for better efficiency, cost effectiveness, resources use, environment and sustainability.
3.2 A Re-Examination of the Aluminum-Air Hybrid Vehicle
John H. Stannard
FCTEK Holdings Ltd.

Abstract
The concept of using aluminum-air semi-fuel cells for motive power in road going EVs originated after the first oil price shocks in the 1970s. A great deal of work was done in North America, largely because of the perceived shortage of petroleum and a desire to make an increasing proportion of transportation energy supply renewable. The work continued into the 1990s and resulted in a number of demonstration vehicles, with the best results being achieved in Canada by Alupower, which at the time was a small spin off of Alcan International Ltd. The demonstration minivan built and operated by Alupower in 1991 was by far the most drivable and realistic expression of this technology and resulted in considerable interest by Nissan, Renault and other companies. At the time of its manufacture it was the world’s longest range EV and was a practical road going vehicle with few concessions to being a hybrid with an Aluminum-air semi-fuel cell combined with a lead acid battery. Range was measured at over 250 km. The economics of the system at that time were not favourable and the technology has remained largely dormant except for niche applications.

A fresh look has been taken at the conceptual design and economics of an aluminum-air range extended vehicle in a study supported by IRAP. The result showed that from a technical perspective that there have been considerable improvements in every aspect of the vehicle design which lead to radically better overall performance and costs. More specifically:
1) Energy consumption is reduced from 290 to 220 Wh/km on an urban delivery driving schedule with a similar vehicle. Overall vehicle performance is improved and payload increases.
2) Aluminum-air system specific energy will improve from 180 to 220 Wh/kg and further improvements in cathode technology will result in 250 Wh/kg.
3) Modern electric vehicle powertrain components are more efficient and much less in weight further improving the overall package. Use of a Lithium-Ion secondary battery improves the weight of the vehicle and will have a better cycle life than previous generation lead-acid batteries. The effective energy density is tripled.
4) The preferred route for anode production is to recycle the spent anodes and alumina hydrate in the electrolyte at an estimated cost of only $1.50/kg for the required purity levels.
5) The best design solution with the lowest life cycle costs employs a Li-Ion unit sized for approximately 60% of all trips and a capacity of approximately 16kWh.
6) Energy costs of the preferred hybrid are substantially lower than an ICE with current fuel costs of $1.20/L. This is a greatly improved result relative to 20 years ago when the technology was not economically viable.

It was concluded from the work carried out that the Aluminum-Air Range Extended Vehicle is technically and economically feasible and a greatly improved result is achieved with modern technology when compared to previous programs.

Poster
Energy and Exergy Analyses of an Integrated PEMFC – Quadruple Effect Absorption Cooling System for Power and Cooling Production for Buildings
T. A. H. Ratlamwala, I. Dincer and M. A. Gadalla

Abstract
In this paper, we propose an integrated proton exchange membrane fuel cell (PEMFC) quadruple effect absorption cooling system (QEACS) system for power and cooling production for residential applications. The effect of temperature, pressure and area of PEMFC on energetic and exergetic COPs, power and cooling production and overall performance of the system are extensively studied. It is found that increasing the temperature of the fuel cell increases the energetic and exergetic COPs from 2.6 to 4.3, and 0.96 to 1.4, respectively. Moreover, with increase in the temperature of the PEMFC the overall exergy efficiency decrease in a bell trend from 0.24 to 0.20. The increase in pressure of the PEMFC results in the degrading performance of the overall system and overall energetic and exergetic efficiencies are found to be decreasing. It is also observed that the increase in the area of the PEMFC affects the performance of the system in a positive way and overall energetic and exergetic efficiencies are found to be increasing. This study reveals that an integrated PEMFC with QEACS cell is an attractive economical and environmental solution for power and cooling production when compared with conventional systems running on fossil fuels.
**Abstract**

A new cell level model for solid oxide fuel cells (SOFCs) with porous composite electrodes is developed. Using this model, entitled the combined micro-macro-model, the microstructural variables of porous composite electrodes can be linked to the cell performance. In this approach, the electrochemical performance of porous composite electrodes is predicted using a micro-model. In the micro-model, the random-packing sphere method is used to estimate the microstructural properties of porous composite electrodes from the independent microstructural variables. These variables are the electrode porosity, particle size ratio, and size and volume fraction of electron-conducting particles. Then, the complex interdependency among the multi-component mass transport, electron and ion transports, and the electrochemical and chemical reactions in the micro-structure of electrodes is taken into account to predict the electrochemical performance of electrodes. The temperature distribution in the solid structure of the cell and the temperature and species partial pressure distributions in the bulk fuel and air streams are predicted using the cell macro-model. In the macro-model, the energy transport is considered for the cell solid structure and the mass and energy transports are considered for the fuel and air streams.

To demonstrate the application of this model, several anode-supported coflow planar cells with a range of microstructures of porous composite electrodes are simulated. The mean total polarization resistance and the temperature distribution in the cells are predicted. The results of this study reveal that there is an optimum value for most of the microstructural variables of the electrodes at which the mean total polarization resistance of the cell is minimized. The microstructure of porous composite electrodes also plays a significant role in the mean temperature, the temperature difference between the hottest and coldest spots, and the maximum temperature gradient in the solid structure of the cell. Overall, using the combined micro- and micro-model, an appropriate microstructure for porous composite electrodes to enhance the cell performance can be designed.
3.4 NSERC H2CAN Network and Hydrogen Safety
Andrei V. Tchouvelev
A.V.Tchouvelev & Associates Inc

Abstract
This presentation informs about the scientific program of the NSERC Hydrogen Canada (H2CAN) Strategic Research Network. H2CAN research activities aim to address all key elements of hydrogen fuel cycle including hydrogen production, purification, storage, infrastructure and safety, taking into account both short- and long-term applications. The presentation will also touch upon relationship between safety and risk, and how hydrogen can be instrumental in achieving uniform safety.

Poster Exergy Analysis of a Solid Oxide Fuel Cell System Operated by Renewable Fuels
Siamak Farhad¹, Alan S. Fung² and Feridun Hamdullahpur¹
¹Mechanical and Mechatronics Engineering Department, University of Waterloo
²Department of Mechanical and Industrial Engineering, Ryerson University

Abstract
The performance of a solid oxide fuel cell (SOFC) combine heat and power (CHP) system for operation with various renewable fuels is studied using computer simulation. The renewable fuels considered are biogas, biomethanol, bioethanol, and biodiesel. The SOFC CHP system studied is mainly composed of an SOFC stack used to generate DC electric power; an air heater used to increase the air temperature before it enters the SOFC stack; an air blower used to overcome the pressure drop in the system; and a burner used to convert the chemical energy of the unutilized fuel in the SOFC stack to heat. Other components of the system are a boiler used to generate hot water for the hot water demand or space heating; a power conditioner used to invert the DC electric power generated in the SOFC stack to AC; and a reformer control volume that may contain a fuel clean-up system, heater, and reformer. Depending on the fuel reforming method employed to prevent carbon deposition on the anode catalyst of the cells in the SOFC stack, this system can have several configurations. In this study, the emphasis is on the anode gas recirculation (AGR), steam reforming (SR), and partial oxidation (POX) fuel reforming methods that make configurations I, II, and III of the SOFC system, respectively. This study is based on exergy analysis and the share of each component of the system in exergy destruction of the input renewable fuel is predicted. The results indicate that the exergetic efficiency of the SOFC system strongly depends on the type of renewable fuel and the fuel reforming method employed. Among the fuel reforming methods, the AGR method yields the highest exergetic efficiency, followed by the SR and POX methods. For configurations I and II of the system, biogas fuel yields the highest exergetic efficiency, followed by biodiesel, bioethanol, and biomethanol fuels. For configuration III of the system, biogas fuel yields the highest exergetic efficiency, followed by biomethanol, bioethanol and biodiesel fuels. The configuration I of the system operated by biogas fuel has the highest exergetic efficiency with 46.5%. The lowest exergetic efficiency is predicted for configuration III of the system operated by biodiesel fuel with 30.1%. The results also indicate that the air heater has the largest share in the exergy destruction of the input renewable fuels.
**Poster**

Optimization and Comparison of Production Methods
# 8 (Precipitation & Spray Pyrolysis) for Direct Sodium Borohydride Fuel Cell (DSBHFC) Anode Catalyst

Osman Okur and Erdogan Alper
Chemical Engineering Department, Hacettepe University

**Abstract**

In this study, the anode electrocatalysis of DSBHFC was produced by precipitation method (PM) and spray pyrolysis methods (SPM). The synthesized electrocatalysis by two methods were compared by physically (XRD, TEM, BET), chemically (cyclic voltametry) and by single cell performance test. The Optimization of preparation parameters for both methods was done by using Design Expert Analysis Program. Seven different Pt based catalysis were synthesized and PtAu one was selected and its optimization parameters was investigated for two production processes. While the preparation temperature (T), pH of the system and drying time were chosen as a parameters for PM; oven temperature and gas flow rate were chosen as parameters for SPM. Experimental data was used for Design Expert Program. At the end of optimization; temperature as 90 oC, system pH as 9,23 and drying time as 61,17 hours were obtained for PM. Oven temperature as 846 C and gas flow rate as 33L/min were obtained for SPM. Particle size, surface area and maximum power density of synthesized catalysis by PM were measured 8 nm, 176 m2/g and 354 mW/cm2 respectively. On the other hand; particle size, surface area and maximum power density of synthesized catalysis by SPM were measured 4 nm, 190 m2/g and 370 mW/cm2 respectively. The electrical efficiencies of synthesized catalysis were obtained as 69,6 % and 60,4 % for PM and SPM, respectively.

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3.5 Non-Precious Metal Fuel Cell Catalysts — the Search for the Holy Grail

E. Bradley Easton
Faculty of Science, University of Ontario Institute of Technology

**Abstract**

Widespread adoption of proton exchange membrane fuel cells (PEMFC) is hindered by various issues. Of critical importance is the reduction or complete elimination of platinum (Pt), which is used to catalyze the electrochemical reactions on both the anode and cathode. Pt reserves are likely to deplete in the event that a large-scale adoption toward PEMFCs occurs. Given its high cost and limited availability, there is great desire to replace Pt with cheaper and more readily available materials. Scientifically, this represents a significant fundamental challenge since Pt-based catalysts are the most active materials known for the oxygen reduction reaction (ORR). Several classes of non-precious metal catalysts (NPMC) are known, with Fe-based catalysts supported on nitrogen-functionalized carbons (Fe/N/C) being the most prevalent to date. However, the exact chemical nature of the active site is still debated, which is not surprising when one considers the lack of chemical control typically used in their synthesis.

Our approach to NPMCs involves the use of surface chemical modification methods in order to more systematically synthesize the Fe/N/C active site. We prepare catalysts using small nitrogen-rich molecules which are covalently attached to a carbon surface via surface specific reactions. This gives us the control required to more precisely create specific active site geometries in high density so that we can better understand the relation between structure and activity. An overview of our methods and results in this area will be presented.
4.1 Electrodes for Direct Utilization of Fossil Fuels in SOFC
Raymond J. Gorte
Chemical & Biomolecular Engineering, University of Pennsylvania

Abstract
SOFC are based on electrolytes that are oxygen-ion conductors and can, in principle, operate on any combustible fuel. However, to allow stable operation with carbonaceous fuels, new electrode materials must be developed. This talk will describe the methods being developed at Penn that allow the electrode composition and structure to be varied easily. By using infiltration methods, it is possible to optimize the selection of electronic conductors and catalysts separately so as to achieve high-performance for gaseous hydrocarbons. Results will also be discussed with molten-metal electrodes for direct utilization of solid fuels. It will be shown that high power densities, > 350 mW/cm² at 700°C, for operation on carbon using molten Sb.

Biographical Sketch
Dr. Raymond J. Gorte joined the faculty at the University of Pennsylvania in 1981 after receiving his PhD in Chemical Engineering from the University of Minnesota. He is currently the Russell Pearce and Elizabeth Crimian Heuer Professor of Chemical & Biomolecular Engineering, with a secondary appointment in Materials Science & Engineering. Since joining Penn, Dr. Gorte has served as Chairman of Chemical Engineering from 1995 to 2000 and was the Carl V. S. Patterson Professor of Chemical Engineering from 1996 through 2001. He received the 1997 Parravano Award of the Michigan Catalysis Society, the 1998 Philadelphia Catalysis Club Award, the 1999 Paul Emmett Award of the North American Catalysis Society, the 2001 Penn Engineering Distinguished Research Award, and the 2009 AIChE Wilhelm Award. He has served as Chairman of the Gordon Conference on Catalysis (1998) and Program Chairman of the 12th International Zeolite Conference (1998). He is an Associate Editor of the Journal of the Electrochemical Society. His present research interests are focused on electrodes for solid-oxide fuel cells and on thermodynamic studies of redox properties with oxidation catalysts. He is also known for his research on zeolite acidity and for metal-support effects, especially with ceria-supported precious metals, used in automotive emissions control.
**Poster** Fine-tuning the Structure and Properties of Sol-Gel based Polymer Electrolyte Membranes
Jesse Allan
Faculty of Science, University of Ontario Institute of Technology

**Abstract**
The technology within a fuel cell has changed immensely over the past 60 years since its first discovery. The platinum loadings have become smaller, as has the fuel cell in general. One aspect of the fuel cell that has not changed however is the Polymer Exchange Membrane (PEM), in which Nafion has been the de facto standard for the past 25 years. With modern advances in new material science, suitable replacements are being sought that can not only compare to Nafion in performance, but improve on it. These new materials are created through a process of Sol-Gel Chemistry, and the membranes created through this process may be able to rival Nafion. The research presented here looks at various techniques of the Sol-Gel process: adding cross-linkers, heat treatment and adding templating agents. All of these processes can greatly influence how the membrane performs and gives a wide degree of control that can allow for a membrane to be created for a suitable purpose.

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**4.2 Direct Ammonia Fuel Cells and Renewable Ammonia for Clean Electricity and Heat**
Andrew McFarlan
Natural Resources Canada

**Abstract**
Anhydrous ammonia (NH₃) is a carbon-free energy carrier, having higher energy density than compressed or liquid hydrogen, and physical properties similar to propane. Extensive infrastructure exists for safely transporting and storing NH₃ due to its established use in industrial refrigeration systems as well as agriculture.

Fuel cell systems operating directly on NH₃ offer essentially zero emissions efficient combined heat and power (CHP) for distributed energy production.

Our research at CanmetENERGY has focused on developing materials, fabricating and testing intermediate temperature fuel cells that operate directly on ammonia. This presentation will highlight our work on direct NH₃ fuel cells using novel proton conducting ceramic materials based on doped barium cerate, as well as conventional solid oxide fuel cell materials which are closer to commercial status. The presentation will also address opportunities and barriers to develop renewable NH₃ production and utilization from non-fossil energy sources in Canada.

**Biographical Sketch**
Dr. Andrew McFarlan is a graduate of University of Ottawa, where he obtained his Ph.D. in Physical Chemistry in 1991. Immediately after graduating he began his career as a research scientist with Natural Resources Canada at CanmetENERGY.

Andy's research has focused on developing cleaner and more efficient industrial processes for converting energy feedstocks such as natural gas or biomass to value-added liquid fuels and chemicals. About 10 years ago, he and his colleagues became interested in ammonia as a carbon-free and potentially renewable fuel, and they initiated an R&D project to develop zero-emissions direct ammonia fuel cells. In addition to ammonia fuel cell development, he has also explored the potential to produce "green ammonia" from renewable energy sources, both for agriculture and energy applications.

Since 2004, Andy has been Manager of the Bioenergy R&D group at CanmetENERGY-Ottawa, and he is a portfolio committee member for NRCan’s Canadian Biomass Innovation Network. Andy also represents Canada at the IEA Bioenergy Task 37, Biogas Production.
4.3 Perovskite Anodes for SOFC

Javier B. Giorgi
Department of Chemistry, University of Ottawa

Abstract

Solid oxide fuel cells (SOFCs) have capabilities to convert chemical energy of fuels into electrical energy with high efficiency and low pollution. However, their high operating temperature and the expensive fabricating cost have significantly limited the development of SOFC towards practical applications. Extensive research is on the way to address these problems. The anode should be able to run SOFCs at lower temperature, and must be resistant towards coke and sulphur poisoning under hydrocarbon fuels. I will discuss some recent developments in my group that address these requirements through novel materials.

Perovskite type oxides (ABO3) have opened a new door to solve the current issues of SOFCs. These perovskites contain a rare-earth metal and transition metals at A-site and B-sites, respectively. The B-site metal provides an active site for the catalysis while the A-site metal is responsible for thermodynamic stability and it also helps in improving the catalytic performance via an interaction with the B-site metal. One of the great advantages of these perovskite materials is that their properties can be easily tailored according to the desired applications, by introducing substitutions at A and B-sites. Additionally, their lattice oxygen plays an important role in carbon cleaning mechanisms via oxygen transport. We have reported that Ce doping in SmFeO3 solves not only the reduction instability problems of the parent perovskite, but also improves its electrical conductivity under reducing conditions by converting the perovskite from a p-type into a n-type conductor. Addition of Co doping in Sm0.95Ce0.05FeO3-δ improves its catalytic properties towards methane oxidation and 3% Co doped has shown optimal performance while being coke resistant. Similarly, Ni doping in Sm0.95Ce0.05FeO3 has shown improved electrical conductivity under reducing conditions. I will discuss the performance of these perovskites as an anode material and explore its coke resistant qualities.

Biographical Sketch

Javier Giorgi is an Associate Professor in the Department of Chemistry at the University of Ottawa. Originally from Argentina, he received his undergraduate degree in chemistry from Concordia University in Montreal and obtained his doctorate from the University of Toronto. His training in surface science under the supervision of Prof. JC Polanyi led to a postdoctoral fellowship at the Fritz Haber Institute of the Max Planck Society with Prof HJ Freund for the study of surface interactions during catalytic processes. Dr Giorgi’s research interests are in catalysis and surface science. The group synthesises and characterises a variety of defective oxides and studies fundamental bulk and surface properties. In recent years, the focus has been on the development of electrocatalytic anodes for solid oxide fuel cell technology. He belongs to the Solid Oxide Fuel Cell Canada (SOFCC) network and has served in the executive of the Ontario Fuel Cell Research and Innovation Network (OFCRIN). Since his arrival at the University of Ottawa in 2002, he has received a Premier’s Research Excellence Award.

Poster

Influence of Composition on the Electrochemical Properties of Sulfonated Organosilane-Based Ceramic Carbon Electrodes for Fuel Cell Systems

Jennie I. Eastcott and E. Bradley Easton
Faculty of Science, University of Ontario Institute of Technology

Abstract

Current commercial fuel cell electrodes contain expensive materials such as platinum catalyst and Nafion® binder. To make fuel cell technology more affordable, these components must be reduced or replaced entirely. Ceramic carbon electrodes (CCEs) are prospective candidates for use in proton exchange membrane fuel cells due to their high surface area, durability, and water retention capabilities. CCEs are comprised of carbon-supported platinum catalyst bound by a ceramic binder material. In this work, the ceramic binder is formed via the sol-gel process using a sulfonated organosilane precursor to give the binder a source of high proton conductivity, similar to Nafion®. We have studied the effectiveness of an electrode binder formed from sulfonated organosilane materials as they are cheaper than Nafion® and may work for a wider range of temperature and humidity conditions. Electrochemical studies (cyclic voltammetry, electrochemical impedance spectroscopy) were conducted to determine effects of proton-conducting functional groups on Pt utilization and proton conductivity. It was determined that incorporating small amounts of sulfonated silane into the CCE structure can lead to a profound enhancement of catalytic activity and proton conductivity despite a sizable decrease in the BET surface area. An overview of materials characterization and fuel cell performance will be presented.
Poster  # 4  Examining In Situ the Oxygen Reduction Reaction Using Density Functional Theory as a Function of Catalyst Support  M.N. Groves¹, C. Malardier-Jugroot¹ and M. Jugroot² ¹Department of Chemistry and Chemical Engineering, Royal Military College of Canada ²Department of Mechanical and Aerospace Engineering, Royal Military College of Canada

Abstract
The proton exchange membrane fuel cell (PEMFC) is still limited by a slow oxygen reduction reaction (ORR) resulting in expensive Pt catalyst loading. By doping the carbon catalyst support there have been both experimental and theoretical evidence that the platinum catalyst activity and durability significantly improves. This work will focus on quantifying these improvements using quantum based methods by first measuring the change in Gibbs free energy (ΔG) of O2 adsorption at the cathode which is a good indicator of the catalyst's activity. Based on these results three different cathodes are modelled for the complete reaction pathway. This includes a two nitrogen doped graphene surface, a single oxygen doped graphene system and a hemoglobin like arrangement using iron centred between four nitrogen atoms in a graphene surface. These three systems are compared against a non-doped graphene/platinum system using density functional theory. According to the ΔG results, the oxygen doped surface will yield the most favourable pathway. We demonstrate that when the full ORR reaction is modelled without water the nitrogen doped system seems to be best suited for this application. It requires the least amount of energy to dissociate water molecules from the platinum catalyst and was shown to have the most favourable activation energies to promote water formation and restrict hydrogen peroxide creation in the water/hydrogen peroxide side reaction. This conclusion is tempered when water is added to the system given that the nitrogen doped system shows hydrophilic tendencies which could alter the different molecular interactions during the reaction. We will present if this, among other considerations, renders one of the other catalyst supports more suitable for fuel cell operation.

Poster  # 1  Cell and System Level Modeling of Solid Oxide Fuel Cell Systems  C. Ozgur Colpan¹, Alan Fung¹, Feridun Hamdullahpur², Ibrahim Dincer³ ¹Department of Mechanical and Industrial Engineering, Ryerson University ²Mechanical and Mechatronics Engineering Department, University of Waterloo ³Faculty of Engineering and Applied Science, University of Ontario Institute of Technology

Abstract
In the first part of this study, a transient heat transfer model to simulate the heat-up and start-up periods of co- and counter-flow direct internal reforming solid oxide fuel cells (SOFC) is developed. In this comprehensive model, all the heat transfer mechanisms, i.e. conduction, convection, and radiation, and all the polarization nodes, i.e. ohmic, activation, and concentration, are considered. The heat transfer model is validated using the results of a benchmark test and two numerical studies obtained from the literature. After validating the model, the heat-up, start-up, and steady-state behaviors of the cell are investigated. In addition, the first principal thermal stresses are calculated to find the probability of failure of the cell during its operation. In the second part of this study, a new conceptual integrated two-stage biomass gasifier and SOFC system is proposed; and a multi-physics model for predicting the performance of this system is developed. The integrated system mainly consists of a rotary dryer, a rotary and inclined kiln as pyrolysis reactor, a downdraft gasifier, a heat recovery steam generator, and a planar and direct internal reforming SOFC. For modeling this system, a method that couples the modeling equations of a quasi 2-D model for SOFC, a 1-D model for pyrolysis reactor, and 0-D model for the remaining components is applied. The effects of several input parameters such as rotational speed of the pyrolysis reactor, number of SOFC stacks, mass ratio of air to steam entering the gasifier, temperature of the preheated air entering the gasifier, and the moisture content of the biomass on the output parameters are studied. The main output parameters of the model are taken as the net power output, useful heat output, electrical efficiency, and the fuel utilization efficiency of the integrated system.
**Poster # 2**

**Systematic Studies of the Cathode-Electrolyte Interface in SOFC Cathodes Prepared by Infiltration**

Rainer Küngas, John M. Vohs and Raymond J. Gorte

Department of Chemical and Biomolecular Engineering, University of Pennsylvania

**Abstract**

SOFC cathodes were prepared by infiltration of La0.8Sr0.2FeO3 (LSF) into porous scaffolds of zirconia-based electrolytes. The polarization resistances of the LSF-electrolyte composites were then examined as a function of the electrolyte conductivity, the electrolyte surface area, and calcination conditions. The results were compared to a theoretical model in order to understand the relationship between electrode structure and performance.

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**Poster # 3**

**Experimental and Modeling Studies of the Flowing Electrolyte – Direct Methanol Fuel Cell**

David Ouellette¹, Yashar Kablou¹, Nasim Sabet¹, Edgar Matida¹, Cynthia A. Cruickshank¹, C. Ozgur Colpan² and Feridun Hamdullahpur³

¹Department of Mechanical and Aerospace Engineering, Carleton University
²Department of Mechanical and Industrial Engineering, Ryerson University
³Mechanical and Mechatronics Engineering Department, University of Waterloo

**Abstract**

Direct methanol fuel cells (DMFCs) are becoming a strong contender for low power applications because of their simple construction, high energy density, and inexpensive fuel. Even though DMFCs hold a promising future, several obstacles still have to be overcome. These include: methanol crossover, carbon dioxide formation, water transport and formation and slow reaction kinetics.

In 2000, Kordesch et al. suggested a novel solution to the crossover problem by implementing a liquid electrolyte, consisting of sulfuric acid, which would flow between the anode and cathode. This, in effect, washes away any crossed-over methanol and water, and thus increases the performance of the cell (since the losses due to methanol and water crossover are reduced). This type of fuel cell is referred to as a flowing electrolyte – direct methanol fuel cell (FE–DMFC).

At Carleton University, experimental and numerical work has been undertaken to increase the performance of a FE–DMFC. Experimental studies on the membrane electrode assembly, the flowing electrolyte channel (FEC), and the pressure drop of the FEC and fuel channels have been carried out for a single cell and stack. Concurrently, single and two-phase semi-empirical and numerical models have been created to verify the accuracy of the experimental results and to test alternative designs.

From these analyses, it has been found that, in a single cell, a 1.5mm porous FEC results in the greatest power density when a 0.5M inlet methanol concentration is used with two Nafion® 212 membranes. It has also been found that the pressure drop inside the inlet manifolds, increase with the stack length and decreases from the first to last cell in the fuel channels; this results in a decreasing volume flow rate along the stack manifolds.