1. Introduction

Staff members involved in fuel cell research at the Nanyang Technological University (NTU) are mainly from the School of Mechanical & Production Engineering (MPE), School of Materials Engineering (SME) and the School of Electrical & Electronic Engineering (EEE). NTU recognizes the importance of this emerging technology, and supports inter-school research efforts in which staff from different backgrounds work together in this multi-disciplinary research area.

Within the School of MPE, the Fuel Cell Strategic Research Programme is being set up with the mission of pursuing fundamental research in fuel cell and fuel reforming, and research into the practical application of the fuel cell system as an economical and efficient alternative for green power and energy.

In MPE alone, there are 8 academic staff members, 1 research fellow, 1 research associate, 7 PhD, 2 MEng and several final year undergraduate students.

2. Objectives

The group's research focuses on two types of fuel cells - high temperature Solid Oxide Fuel Cells (SOFC, also known as Ceramic Fuel Cells) and low temperature Polymer Electrolyte Membrane Fuel Cells (PEM, also known as Proton Exchange Membrane Fuel Cells), in a variety of applications, including distributed and stationary power and cogeneration applications; transportation applications; and small scale power applications. The group's objectives include:-

- fundamental fuel cell research to promote the development of improved, next generation fuel cells, including studies on materials, cell configurations and design, and electrochemical, heat and mass transfer processes, electrode design, micro-modeling of electrodes and electrolyte
- applied research related to the practical and economic application of fuel cell systems, including technology testing, proving and demonstration; system modeling and optimization; techno-economic and feasibility studies on fuel cell applications
- important technologies related to the practical use of fuel cells, including reforming of conventional and alternative fuels.

3. Research and Development
1. Solid Oxide Fuel Cells – Development of YSZ, LSGM, GDC-based SOFC; Development of electrolyte and electrodes-supported fuel cell; Development of multi-layered electrolyte and electrode system; Introduction of doped-bismuth oxide for electrolyte fabrication; Application of plasma spray to cell components fabrication; Development of high ionic conductivity electrolyte using spark plasma sintering technique (We achieve 0.16 – 0.17 S/cm at 1000°C with YSZ electrolyte); Development of high-performance intermediate-temperature SOFC (We achieve 0.93 W/cm² at 800°C, anode-supported Ni-YSZ|YSZ|LSM-YSZ SOFC); Modeling of charge transfer and migration in electrolytes; Modeling of electrode microstructure and its effect on the electrochemical reaction and transport phenomena; etc.

2. Proton Exchange Membrane Fuel Cells – Design and fabrication of membrane-electrodes-assembly (MEA); Design and fabrication of hydrogen and oxidant flow channels (straight and serpentine flow channels and screen flow field); Development of PEM fuel cell stacks; Experimental investigation of the effect of long flow channel on the performance of PEM fuel cell stack; Thin-film deposition of catalyst on electrode with magnetron sputtering system; Modeling of PEM fuel cell with emphasis on protonic transfer across Nafion membrane, water transport across MEA, heat transfer and carbon monoxide poisoning; Development of 2-D and 3-D PEM fuel cell codes, etc.

3. Fuel Processing – Development of Ni and Cu based catalyzed autothermal fuel reformer and facility for methanol and natural gas reforming; Development of novel water-gas shift enhanced mini-reformers for portable fuel cell stack application; Development of hardware natural gas simulator for studying the effect of natural gas composition on the maximum hydrogen yield; Development of chemical kinetic test rig for the study of partial oxidation and steam reforming processes; Experimental investigation of the dynamic behavior of the reformers; Modeling of autothermal fuel reformer with emphasis on reaction kinetics; Thermodynamic analysis of autothermal reformer under thermo-neutral condition; Investigation of the effect of air-fuel and water-fuel ratios on the maximum hydrogen yield under the constraints of minimized CO and residual fuel and free from solid carbon formation; Investigation of the effect of natural gas compositions on the reformate by simulation technique.

4. Simulation of fuel cell and integrated fuel cell-gas turbine power systems – Energy and exergy analysis of a simple SOFC power system; Simulation of hybrid fuel cell-gas turbine power and co-generation plants; Techno-economical assessment of fuel cell systems and plants in transportation and stationary (distributed) power generation applications, with emphasis on the energy efficiency and environmental benefits of fuel cell systems.

4. Facilities

Our experimental activities are mostly carried out in Fuel Reforming Lab for thermochemical fuel reforming study, Fuel Cell Lab for fuel cell fabrication, performance evaluation and electrochemical analysis and Materials Lab for materials processing and characterization. In addition, we are also active users of Advanced Materials Research Centre.

Fuel Reforming include facilities for methanol and natural gas reforming, chemical kinetic test rig for reforming processes and catalyst study, natural gas simulator, mass spectrometer, non-dispersive infrared emission analyzers for carbon monoxide, carbon dioxide and unburned hydrocarbon measurement, thermal conductivity based analyzer for hydrogen measurement, flame ionization detector for unburned hydrocarbon measurement, chemiluminescence analyzer for oxides of nitrogen measurement, tapered element oscillating microbalance (TEOM) for soot particulate measurement, gases sampling system with Nafion dryer, etc.
Fuel Cell facilities include a wide range of electrochemical analytical equipments (Solartron, Autolab and Gamry) for low frequently high current and high frequently low current device applications, and fuel cell test stations for PEMFC (Electrochem) and SOFC (in-house-built). Our fuel cell and components are fabricated using spark plasma sintering equipment, robotic assisted plasma spraying system, ultrasonic spraying system, magnetron sputtering system, spin coater, tape caster, screen printer, etc. Characterization equipment includes dilatometer, Scanning electron microscope (SEM), X-Ray fluorescence (XRF) spectrometer, X-Ray Diffractometer (XRD), etc. Some of these equipments are located at Advanced Materials Research Centre (AMRC) (http://www.ntu.edu.sg/sme/Labssme/labssme.html#AMRC).

In addition, to support modeling and simulation works, our software and modeling resources include ASPEN, GATE-CYCLE, and general purpose engineering and mathematical software such as MATLAB/SIMULINK, MAPLE and MATHEMATICA.

5. Future Plans

We will continue to achieve research excellent in fuel cell and fuel reforming and is tasked with conducting fundamental research on one hand, and development and demonstration of technologies on the other hand. Recognizing the importance of this technology, Fuel Cell SRP sets its sights on establishing itself as the regional centre for fuel cell technology through this multidisciplinary strategic research.

We will continue to collaborate closely with government agencies, local and international organizations and companies and world renowned universities and fuel cell research centers. Initiatives related to public outreach, and training and education of manpower in the fuel cell area are also being pursued, with the realization that such activities will also have a critical role in our efforts to establish Singapore and NTU as a focal point for fuel cell research in the ASEAN and Asia-Pacific region.

6. Publications


S.P. Jiang, J.P. Zhang and X.G. Zheng, A comparative investigation of chromium deposition at air electrodes of solid oxide fuel cells, J. European Ceramic Soc. (in print)


S.H. Chan, H.K. Ho, Y. Tian, Modelling of simple hybrid solid oxide fuel cell and gas turbine power plant, *J. Power Sources*. (in print)


[Design and fabrication of PEMFC stack]
Hybrid SOFC-GT Power System

Chan, S.H