On the Use of Phosphoric Acid-Doped Polybenzimidazole as a Membrane in a Thermally Regenerative Fuel Cell

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Background Information and Objectives

With 11 million medium and heavy trucks on US roads in 2008 and 684,000 new trucks added that year alone, there are substantial economic incentives to increase the fuel economy of the transportation industry [1]. This research proposes that a thermally regenerative fuel cell could replace the alternator in long haul transport trucks and provide power generation for auxiliary systems as well as heat removal for the engine block.

The proposed TRFC selectively hydrogenates propiophenone at the fuel cell to produce 1-phenyl-1-propanol and then regenerates the fuel in an external dehydrogenation reactor using waste heat scavenged from an internal combustion engine.

In this work the performance of the TRFC system was evaluated. A analysis of the effect of propiophenone immersion on the conductivity of phosphoric acid-doped PBI membranes was also carried out using electrochemical impedance spectroscopy.

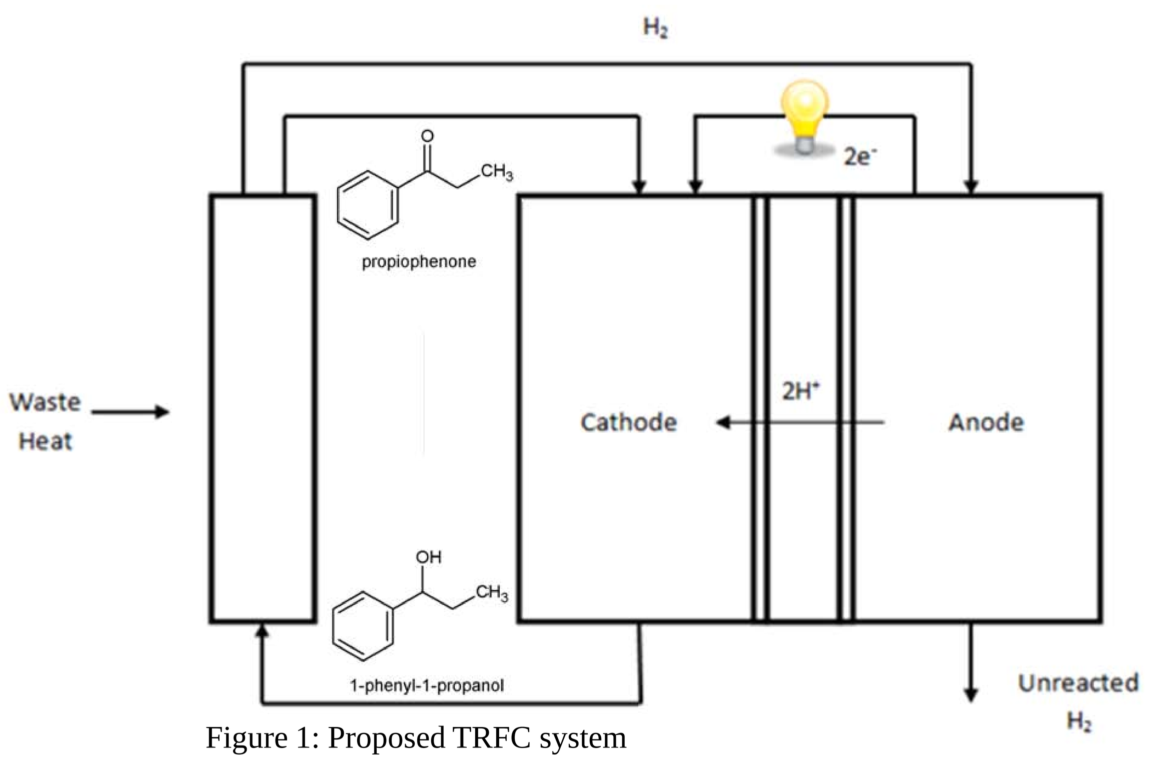

Figure 1: Proposed TRFC system

Experimental Methods

TRFC Performance Testing

TRFCs were assembled using commercial phosphoric acid-doped PBI MEAs with platinum catalyst loadings of 0.33 mg/cm² and 1.07 mg/cm² on the anode and cathode respectively (Danish Power Systems). Current was drawn using passive resistors between 1Ω and 2200Ω. Results were validated using linear sweep voltametery. A scan rate of 0.0001V/s was used to scan between open circuit voltage and 0V. Propiophenone was heated to fuel cell temperature and fed to cathode; hydrogen was fed to cathode. Voltage was monitored using an Arbin BT-2000 multi-channel battery testing station. Hydrogenation reaction products were analyzed using a Shimadzu GC-17A gas chromatograph.

PBI Membrane Conductivity Testing

Experimental method was based on a literature method [2]. Phosphoric acid-doped PBI membranes (Danish Power Systems) were immobilized within a Nylon support and analyzed using a Biologic SP 150 potentiostat. Voltage perturbations of ±5mV were applied across a voltage of 0V. The frequency range was 500kHz to 100mHz. Membranes were immersed in propiophenone at various temperatures and a number of EIS spectra were obtained over a period of a few hours

Results and Discussion

TRFC Performance

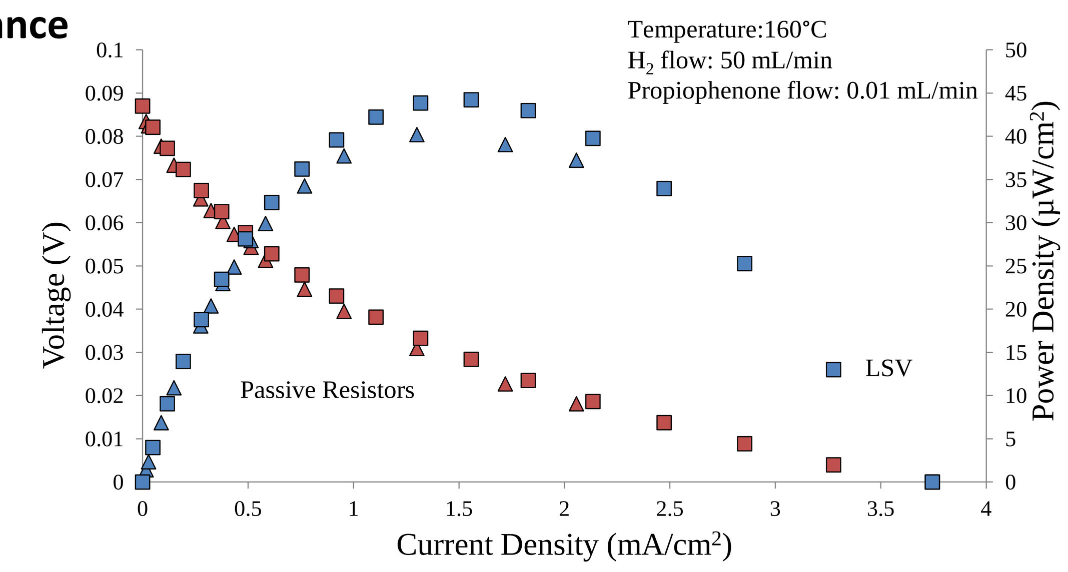

Figure 3: Performance of TRFC1 – comparison of results from passive resistor and linear sweep voltammetry methods

Results and Discussion

TRFC Performance

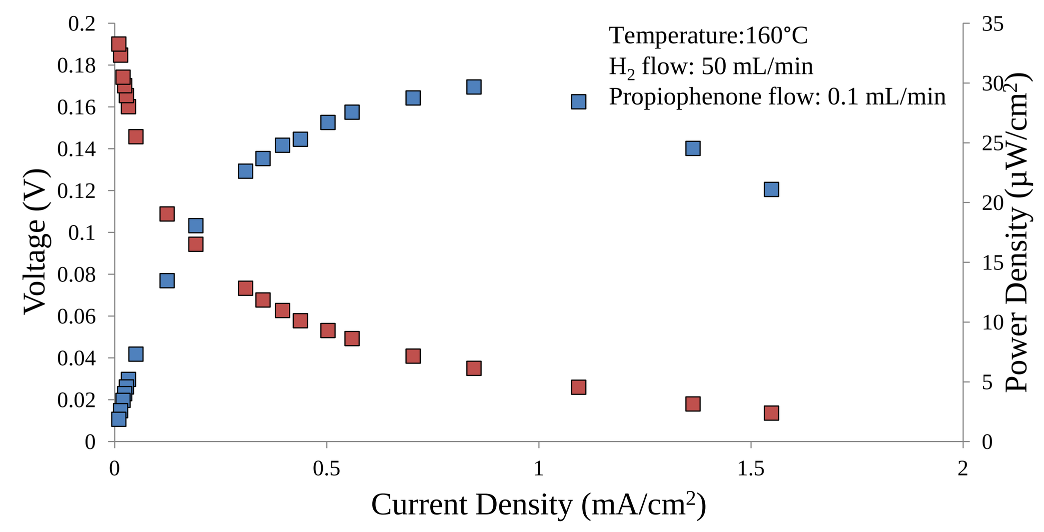

Figure 4: Performance of TRFC2

The maximum TRFC performance was approximately 40 μW/cm². The open circuit voltage of the TRFC has varied inexplicably from cell to cell between 0.19V and 0.09V. GC analysis of the hydrogenation product showed that no 1-phenyl-1-propanol was being produced, however, tiny amounts of some unidentifiable compounds were observed. The amount of observed hydrogenation products was smaller than was expected based on observed amount of hydrogenation.

Membrane Conductivity

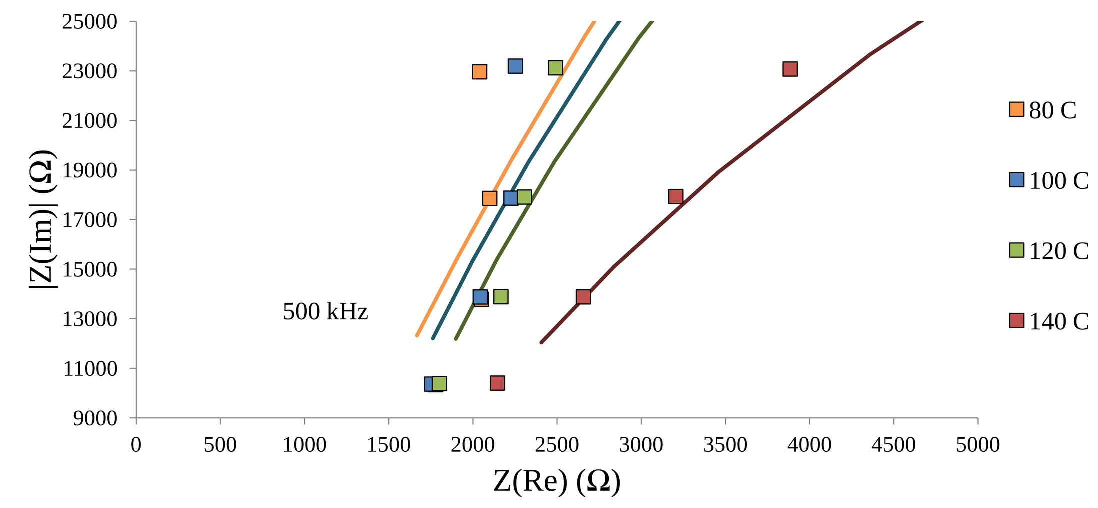

Figure 5: Low frequency Nyquist analysis of phosphoric acid-doped PBI (doping level 2.81) in propiophenone

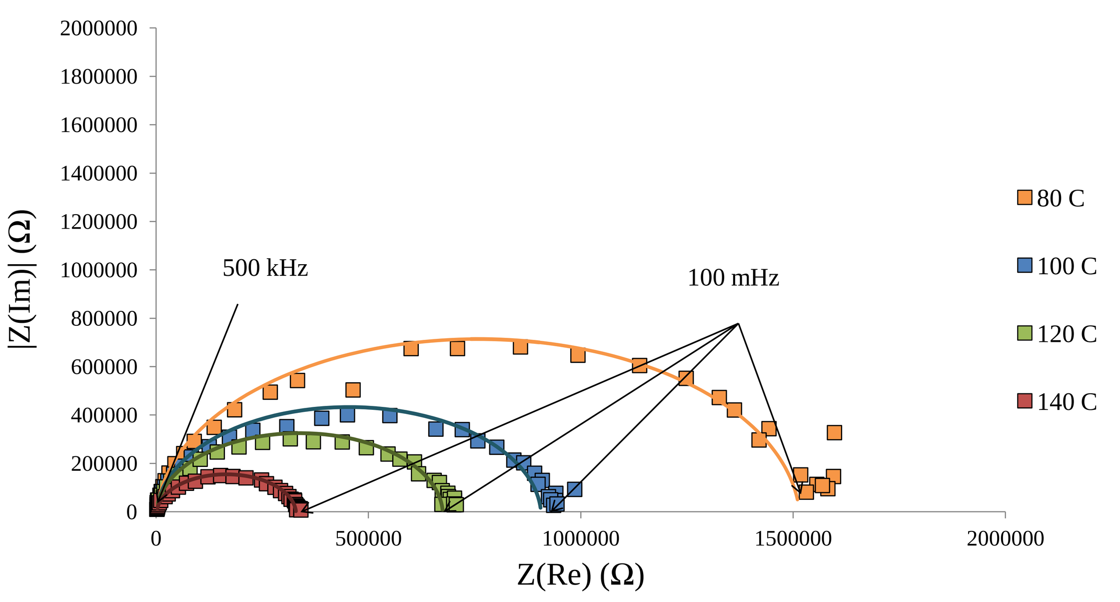

Figure 6: Nyquist analysis of phosphoric acid-doped PBI (doping level 2.81) in propiophenone

Table 1: Resistance and conductivity of phosphoric acid-doped PBI (doping level 2.81) in propiophenone

T (°C)	Average Resistance (Ω)	Average Conductivity (S/cm)
82.9	838.9	0.275
98.1	1048.6	0.220
121.5	1232.2	0.187
139.2	1277.5	0.181

Severe membrane degradation was observed in many trials. Post-testing, membranes were extremely brittle and broke with minimal force. Brittleness subsided over time, with membranes returning to normal after a few days.

Future Work

- Further TRFC trials to validate the observed OCV variance
- Determination of the mechanism by which PBI is degrading when exposed to the TRFC conditions
- Locating a set of organic compounds that will not degrade PBI membranes

References

1. Cooper, C., Kamakate, F., Reinhart, T., Kromer, M., & Wilson, R. (2009). *Reducing heavy-duty long haul combination truck fuel consumption and CO2 emission.*
2. Soboleva, T., Xie, Z., Shi, Z., Tsang, E., Navessin, T., & Holdcroft, S. (2008). Investigation of the through-plane impedance technique for evaluation of anisotropy of proton conducting polymer membranes. *Journal of Electroanalytical Chemistry*, 145-152.

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