Hydrogen + Fuel Cells 2011: International Conference and Exhibition, Convention Centre in Vancouver, May 15-18, 2011

A DIRECT DME FUEL CELL BASED ON ACID DOPED PBI AT AMBIENT PRESSURE

Jens Oluf Jensen[1]*, Anton Vassiliev[1], Qingfeng Li[1], Martin Ingemann Olsen[1], Chao Pan[1], Thomas Steenberg[2] and Niels J. Bjerrum[1]

[1] *Energy and Materials Science Group, Department of Chemistry, Technical University of Denmark, Kemitorvet 207, DK-2800 Kgs. Lyngby, Denmark*

[2] *Danish Power Systems®, Raadhusvej 59, DK-2920 Charlottenlund, Denmark*

**joj@kemi.dtu.dk*

Abstract

A high temperature polymer fuel cell was operated as a vapour fed direct dimethyl ether (DME) fuel cell at ambient pressure and with air as oxidant. A peak power density of 67 mWcm^{-2} was measured at 200°C. Conventional polymer based direct DME fuel cells are liquid fed and suffers from low DME solubility in water. When the DME-water mixture is fed as vapour miscibility is no longer a problem.

Dimethyl ether (DME)

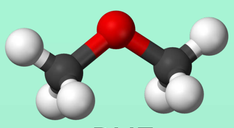
DME is:
- A clean colourless gas
- Liquid at 6 bar(a) - handled like LPG
- Little or not toxic
- Not a greenhouse gas
  (Decompose in atmosphere in tens of hours)

As a fuel:
- Excellent diesel engine fuel
- Burns with no particulate matter (soot)
- Cetane rating 55 – 60
  (45 for petroleum-derived diesel)

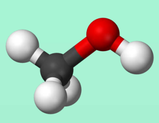
Other uses:
- Aerosol propellant
- Cooking gas

Manufacture (like methanol):
- From biomass
- From hydrogen and CO

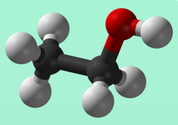
Direct conversion in a PEMFC?



DME



Methanol



Ethanol

	Methane	Methanol	Dimethyl ether	Ethanol	Gasoline	Diesel
Formula	CH_4	CH_3OH	CH_3OCH_3	CH_3CH_2OH	C_7H_{16}	$C_{14}H_{30}$
LHV (kJ cm^{-3})	0.0346	15.82	18.92	21.09	32.05	35.66
LHV (kJ g^{-1})	47.79	19.99	28.62	26.87	43.47	41.66
Boil.p (◦C)	−162	64	−24.9	78	38–204	125–400

DME powered diesel truck from Volvo

Concept

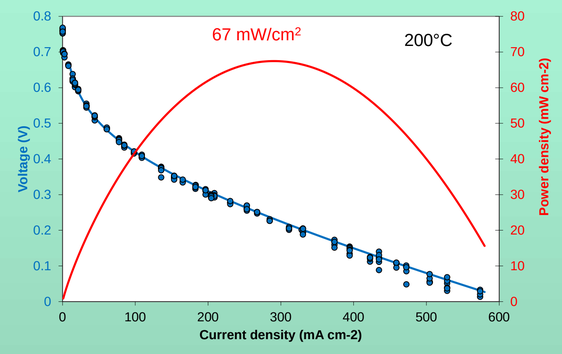
The idea is to increase the working temperature of the cell above the boiling point of water and feed the DME-water mixture as vapour. Then **miscibility** is not a problem.

For this a **high temperature polymer fuel cell (HT-PEMFC)** based on a membrane of acid doped polybenzimidazole (PBI) is applied.

A fuel cell system based on phosphoric acid doped polybenzimidazole (PBI) was first presented in 1995 (*11*).

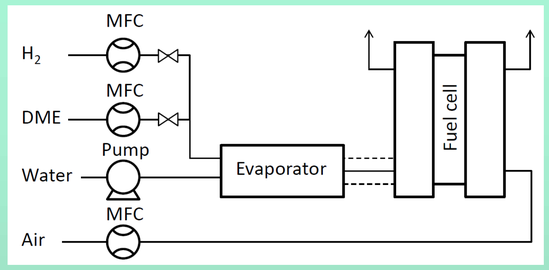
It has been developed further (*12*) and even entered an early stage of commercialization by companies like BASF Fuel Cells and Danish Power Systems. The working temperature can be 120-200°C

Results

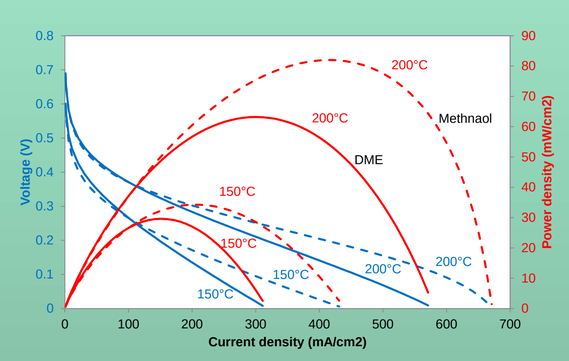


Polarization curves of a direct DME fuel cell based on acid doped PBI at 200°C. Ambient pressure, air as oxidant.

Anode catalyst: PtRu/C (Johnson-Matthey, 1:1, 60 wt%, 3.7 mg metal pr cm^2)
Cathode catalyst: Pt/C (in house, 40 wt%, 0.7 mg Pt pr. cm^2)



Schematic setup



A similar cell. Comparison of direct fuelling with DME and methanol

Challenges for direct DME PEMFC

Like in direct methanol fuel cells DME is normally fed as an aqueous solution

Anode reaction: $CH_3OCH_3 + 3H_2O \rightarrow 2CO_2 + 6H^+ + 6e^-$

DME-water ratio 1:3 ⇒ 46 %wt solution of DME in water, but DME solubility in water is only ca. 7.6 %wt at 20°C(*2*).

At 80°C of a traditional polymer fuel cell the solubility is even lower and a saturated DME-solution separates into two phases (*3*). This impedes the process.

Peak power densities reported with conventional polymer fuel cells:
- Ambient pressure, air as oxidant: 20 to 40 mW/cm (*3-5*).
- Ambient pressure, pure oxygen: 30 to 56 mW/cm (*6-10*).

For most applications only air is available.
The two-phase problem can in principle be mitigated by pressurizing the system, but this consumes energy and is not an attractive option for direct fuel cell systems which are meant to be simple.

One of the serious drawbacks of direct methanol fuel cells is the methanol crossover. DME crossover is expected to be less pronounced due to the lower solubility in a hydrophilic environment.

Conclusion

- A high temperature polymer fuel cell for direct DME allows for vapour fed operation.
- This solves the problem of phase separation.
- A peak power density of 67 mW/cm^2 at 200°C with air as oxidant.
- Highest peak power density reported to date for a DME polymer fuel cell at ambient pressure.
- High open circuit voltage indicates that crossover seems less than for direct methanol cells.

References

Further on DME:

http://www.aboutdme.org

1. T. A. Semelsberger, R. L. Borup, H. L. Greene, *J. Power Sources* **156**, 497 (Jun, 2006).
2. J. T. Muller *et al.*, *J. Electrochem.Soc.* **147**, 4058 (Nov, 2000).
3. R. H. Yu, H. G. Choi, S. M. Cho, *Electrochem. Comm.* **7**, 1385 (Dec, 2005).
4. M. M. Mench, H. M. Chance, C. Y. Wang, *J. Electrochem. Soc.* **151**, A144 (Jan, 2004).
5. J. Y. Im, B. S. Kim, H. G. Choi, S. M. Cho, *J. Power Sources* **179**, 301 (Apr, 2008).
6. Y. Tsutsumi, Y. Nakano, S. Kajitani, S. Yamasita, *Electrochem.* **70**, 984 (Dec, 2002).
7. K. D. Cai, G. P. Yin, L. L. Lu, Y. Z. Gao, *Electrochem. Solid State Letters* **11**, B205 (2008).
8. I. Mizutani, Y. Liu, S. Mitsushima, K. I. Ota, N. Kamiya, *J. Power Sources* **156**, 183 (Jun, 2006).
9. S. Ueda, M. Eguchi, K. Uno, Y. Tsutsumi, N. Ogawa, *Solid State Ionics* **177**, 2175 (Oct, 2006).
10. Y. Zhang, Y. J. Tong, L. L. Lu, M. Osawa, S. Ye, *J. Electrochem. Soc.* **157**, F10 (2010).
11. J. S. Wainright, J. T. Wang, D. Weng, R. F. Savinell, M. Litt, *J. Electrochem. Soc.* **142**, L121 (Jul, 1995).
12. Q. F. Li, J. O. Jensen, R. F. Savinell, N. J. Bjerrum, *Prog. Polym. Sci.* **34**, 449 (May, 2009).

Acknowledgements

- The Danish Agency for Science, Technology and Innovation (Vedvarende Energiteknologier)
- The ForskEL program (HotMEA)