Improving Lifetime Performance of SOFC for Truck APUs

(Förbättringar av livslängden av fastoxidbränsleceller-APU för tunga fordons applikationer)

Hannes Falk Windisch, Jan Froitzheim and Jan-Erik Svensson

Energy and Materials
Chemistry and Chemical Engineering
Chalmers University of Technology
Outline

Part I: Overview SOFC Technology

Part II: Recent results from the FFI project
Solid Oxide Fuel Cell (SOFC)

Advantages
- High electrical efficiency
- \( \text{O}^{2-} \) conductive electrolyte
  - Fuel flexibility (\( \text{H}_2 \), natural gas, biogas, diesel)
- High operating temperature
  - No need for expensive catalysts such as Pt

The electrolyte is a oxygen ion conducting material (600-900 \(^\circ\)C)
SOFC as APU for mobile applications

350k+ Heavy Duty Trucks in the US

Produce 11 Mt CO$_2$, 18 kt NOX, 5 kt particulate matter

Electrical efficiency: 4%

**SOFC APU:**
Fuel: Diesel
Function: cabin climatisation, electrification, engine pre-heating

Electrical efficiency$: 30%$

$^{1}$http://www.desta-project.eu/desta-project/
Nissan Unveils World’s First Solid-Oxide Fuel Cell e-NV200

- A electric car with a 5 kW SOFC system and a 30 liter thank for bio-ethanol.
- Range: 600 km (compared to 170 km without the SOFC range extender)

Nissan has finalised an agreement with Horsham-based Ceres Power (SOFC) to develop fuel cell technology that will be an alternative to hydrogen.

Range is a limiting factor for electric vehicles at the moment.

http://www.proactiveinvestors.co.uk/companies/news/127565/ceres-powers-up-alongside-nissan-127565.html?platform=hootsuite
The FFI project

Project partners

- Sandvik
- Avancez
- CHALMERS
- ELCOGEN
- Volvo
Objectives

Improving Lifetime and Performance of SOFC for Truck APUs
- In a cost efficient way

- Improve oxidation resistance at the cathode and the anode side
- Reduce chromium evaporation
- Reduce costs! Cheaper steel, cheaper coating methods
Solid Oxide Fuel Cell (SOFC)

Electrolyte supported  Anode supported  Metal supported

>800°C  650-800°C  500-700°C

There is a general trend towards lower operating temperatures.

⇒ Possibility to use less expensive materials
⇒ Higher efficiency possible
⇒ Longer lifetimes
⇒ Faster heating/cooling
Solid Oxide Fuel Cell (SOFC)

Anode supported

650-800 °C
Solid Power
(SOFCpower and Ceramic Fuel Cells)

60% net AC
(74% DC single pass)
Incorporated the larger-scale SOFC components into fuel cell stacks as large as 60 kilowatts (kW).
Our project partner is Elcogen

Elcogen is a Finnish/Estonian SOFC developer selling cells and stacks

Single cells 1 kW stack 3 kW stack
Outline

Part I: Overview SOFC Technology

Part II: Recent results from the FFI project
Cost analysis 1 kW Stack

1 kW Stack Manufacturing Cost (50 000 Units)

- Cells
- Interconnects
- Sealing, End plate etc
- Assembly Hardware

35%

*Source: Battelle study prepared for US DOE (2014)*
Ferritic \text{Cr}_2\text{O}_3\text{-forming steels as interconnect material in SOFC}

- Similar thermal expansion as the ceramics used in SOFC
- Good electrical and thermal conductivity
- Form conductive oxide scales (\text{Cr}_2\text{O}_3)
- Formability
- Cheap to produce
However

Steel (FeCr)

$\text{O}_2 + \text{H}_2\text{O}$

oxidation

600-900 °C

Steel (FeCr)

CrO$_2$(OH)$_2$(g)

Oxide scale growth $\rightarrow$ increased electrical resistance

Cr vaporization: $\text{Cr}_2\text{O}_3(s) + \text{O}_2(g) + \text{H}_2\text{O}(g) \rightarrow \text{CrO}_2(\text{OH})_2(g)$

$\rightarrow$ Cathode poisoning
How to reduce Cr vaporization?

Our approach apply metallic nano coatings:

Steel (FeCr) + O₂ + H₂O → Cr₂O₃ + 600-900 °C

Co + O₂ + H₂O → Co₃O₄ + 600-900 °C
Cr vaporization
Air, 850 ºC

Accumulated Cr vaporization (kg/m²)

Exposure time (h)

x10 reduction

Uncoated

Co coated (600nm)

Solid Oxide Fuel Cell (SOFC)

Electrolyte supported

Anode supported

Metal supported

>800°C

650-800°C

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Oxide scale growth

$E_a: 270 \text{ kJ/mol}$

Exposure temperature ($^\circ$C)

Cr vaporization

$E_a: 90 \text{ kJ/mol}$

Evaporated Cr after 500 h (mg cm$^{-2}$)

Significantly slower oxide scale growth rate at lower temperature

Much smaller decrease in Cr vaporization rate

=>$\text{Coatings are necessary also at lower temperatures (650 °C)}$
Comparison Sandvik thin-film Ce/Co coating and Elcogen standard coating

Both materials significantly mitigates Cr vaporization at 650 °C
Comparsion Sandvik thin-film Ce/Co coating and Elcogen standard coating

Very low ASR for both materials (lowest for Sandvik thin-film Ce/Co coating)
Summary Part 1

On a component level Sandvik Ce/Co thin-film coatings performed as good, or even better then the standard Elcogen coating

Part 2 is to decrease steel costs

By using standard stainless steels, the price of the interconnect can be reduced significantly! (factor 10)
Part 2: Substituting the expensive steel to a cheap standard stainless steel

No difference in oxide scale thickness (and ASR) was observed as the expensive steel was substituted to a cheap steel after 500 h at 650 °C.
Lab results very promising, however,.....

Cheap steel, cheap coating

660 °C

Performance drop

Fist stack test, not as successful as hoped for

Why?
Development of new test method

Simulated stack environment
Dual atmosphere effect

H₂ on the anode side suppresses the ability for the steel to form a protective chromia scale on the cathode side at low temperature.
Summary and future work

• Decreasing the SOFC operating temperature has many advantages

• Component studies showed promising results for the low-cost steel AISI 441 coated with Sandvik thin-film Ce/Co coating

• First stack test (cheap steel, cheap coating), not as successful as hoped for

• New stack test (ongoing) with cheap coating but expensive steel (Elcogen standard steel)

• A fundamental understanding of the dual atmosphere effect is necessary in order to be able to allow for low-cost materials.

More research needed!!!
Bevakningsuppdraget

Thank you,

Going to these fuel cell conferences during my PhD have helped me to do better and more relevant research.