Solid Oxide Fuel Cells: cell and stack technology

August 23, 2011 | Izaak C. (Ico) Vinke

contents

- requirements
- applications
- stack design
  - cell configurations
  - charge transport
  - mass transport
  - heat management
- some examples
  - tubular
  - planar
  - industrial developments
SOFC: cell and stack requirements

are governed by the system requirements, which, in turn, are governed by the application:

- size demand for $kW_e$
- operation dynamic load-following vs. stationary base-load
  operation time vs. degradation rate
  fuel availability

in the end, however, it will all come down to

- cost of investment
- cost of operation

SOFC: systems applications and sizes

- mobile
  - hand held < 1kW personal power e.g. military application
  - μ-CHP 1-5 kW recreational, camper

- APU
  - cars 5-10 kW stationary heating, onboard electronics
  - trucks 5-50 kW idling reduction, refrigeration
  - planes 50 kW noise reduction, water generator
  - ships 10-250 kW port power

- stationary
  - μ-CHP 1-5 kW single houses
  - CHP 10-250 kW hospitals, distributed power
  - power plant > 1 MW centralized power production
### SOFC: systems applications and operation

<table>
<thead>
<tr>
<th></th>
<th>SOFC: cell and stack technology</th>
<th>APU for cars (5-10 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>operation time</td>
<td>40,000 hours</td>
<td>5,000 hours</td>
</tr>
<tr>
<td>degradation</td>
<td>&lt; 1% in 1000 hours</td>
<td>&lt; 10% in 1000 hours</td>
</tr>
<tr>
<td>cycling</td>
<td>&gt; 50 (thermal)</td>
<td>&gt; 250 (thermal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 250 (red-ox)</td>
</tr>
<tr>
<td>start up</td>
<td>4-5 hours</td>
<td>&lt; 10 minutes</td>
</tr>
<tr>
<td>cost</td>
<td>$ 100/kW for stack</td>
<td>$ 50/kW for stack</td>
</tr>
</tbody>
</table>

### SOFC: stack design

- **Fuel**: H₂, CO, CH₄, CO₂, H₂O
- **Oxidant**: O₂
- **Exhaust**: H₂, CO₂, H₂O
- **Coolant**: warm, hot
SOFC: stack design

is solving the puzzle

taking into account
- the materials used for the components
- the manufacturing technologies used
- the cell configuration selected
- the processes for
  - charge transport short current paths, no short-circuiting
    good electrical contacts and sufficient contact area
  - mass transport no gas leakages, no cross-leakages
    uniform distribution of reactants, not only across the
    area of each cell but also to each cell of the stack
  - heat transport appropriate gas flow configurations for stack cooling,
    more uniform temperature distribution during operation
- mechanical/structural integrity adequate mechanical strength for assembly,
  handling and during operation
  minimise mechanical and thermal stresses
### SOFC: Cell Configurations

<table>
<thead>
<tr>
<th>Tubular</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>high mechanical strength</td>
<td>low(er) power density</td>
</tr>
<tr>
<td></td>
<td>no high-temperature seals</td>
<td>high(er) manufacturing costs</td>
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<table>
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<tr>
<th>Planar</th>
<th>Electrolyte = supporting component</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>high(er) power density</td>
<td>limited mechanical strength</td>
<td></td>
</tr>
<tr>
<td></td>
<td>low(er) manufacturing cost</td>
<td>high-temperature seals require</td>
<td></td>
</tr>
</tbody>
</table>

- **Electrolyte**: Inert ceramic
- **Anode**: Planar or tubular
- **Cathode**: Planar or tubular

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Institute of Energy and Climate Research: Fundamentals of Electrochemistry (IEF-9)
1st Joint European Summer School on Fuel Cell and Hydrogen Technology
Aug 22 - Sep 2, 2011, Viterbo, Italy

SOFC: cell and stack technology
SOFC: cell configurations

- **Tubular**
- **Planar**

**Electrolyte**

**Anode**

**Cathode**

**Inert Ceramic**

**Metal**

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SOFC: cell configurations

- tubular
- flattened tubular
- planar

SOFC: stack design and charge transport

electrical connection of cells:

- in series and in parallel
- in series
SOFC: stack design and charge transport

electrical connection of cells:

- in series

interconnector

contact element

- larger conducting cross section
- shorter distance between contact points
- larger contact area

- smaller conducting cross section
- longer distance between contact points
- smaller contact area

SOFC: stack design and mass transport

fuel and air supply:

- to all cells in a stack
- over the cell (electrode) area
- in the (porous) electrode to the electrode/electrolyte interface (e.g. the reaction sites)
- fuel vs. air

manifolding (Z- or U-type)

- external
- internal (integrated)

- parallel
- serpentine (meander)
- radial
- spiral

flow configuration

- co-flow in same direction
- counter-flow in opposite directions
- cross-flow in directions usually differing 90°
SOFC: stack design and mass transport

fuel and air supply:
- to all cells in a stack

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- external
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source: Th. Wüster, Ph.D. Thesis, RWTH Aachen

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SOFC: stack design and mass transport

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**SOFC: stack design and mass transport**

**fuel and air supply:**
- to all cells in a stack
- over the cell (electrode) area

**manifolding (Z- or U-type):**
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**flow field:**
- parallel
- serpentine (meander)
- radial
- spiral

**fuel and air supply:**
- fuel vs. air

**flow configuration:**
- co-flow in same direction
- counter-flow in opposite directions
- cross-flow in directions usually differing \( \angle \)°

**Temperature / °C:**
- has direct effect on current and temperature distribution

**Heat management**
SOFC: stack design and mass and heat transport

heat production
- electrochemical reactions ($T\Delta S$)
- current ($I^2R$)

cooling
- air mass flow (stoichiometry > 2)
- internal reforming of methane (endothermic)

SOFC: some examples of stack concepts
SOFC macro tubular cells / stacks

- cathode supported tubes with one cell per tube
- anode supported tubes with one cell per tube
- inert supported tubes with multiple cells

**Advantages:**
- low degradation
- relatively easy sealing
- pressurized operation
- for multiple cells: high output voltage

**Disadvantages:**
- high temperature 900-1000°C
- low power density < 0.3 W/cm²
- low heating rates

SOFC: micro tubular cells / stacks

- electrolyte supported

  **Advantages:**
  - high heating rates
  - moderate power density ~0.5 W/cm² (low degradation?)

  **Disadvantages:**
  - high temperature ~900°C
  - low power per cell
  - complex manifolding and sealing

- anode supported

  **Advantages:**
  - moderate power density ~0.5 W/cm²
  - medium temperatures 700-800°C

  **Disadvantages:**
  - low power per cell
  - complex manifolding and sealing
  - redox instable
SOFC: micro tubular cells / stacks

- micro tubular anode supported
- advantages:
  - low temperature 500-600°C
  - high power density > 1 W/cm²
  - (high heating rates)
- disadvantages:
  - low power per cell
  - complex manifolding and sealing cooling problems
- monolithic
- advantages:
  - low temperature 600-700°C
- disadvantages:
  - low power density < 0.4 W/cm²
    - (complex manifolding and sealing)

SOFC: planar cells / stacks

- electrolyte supported with ceramic interconnect
- advantages:
  - low degradation
- disadvantages:
  - high temperature ~900°C
  - low power density < 0.3 W/cm²
  - complex sealing geometry
  - complex manufacturing
SOFC: planar cells / stacks

- Electrolyte supported with metallic interconnect
  
  **Advantages:**
  - Red-ox stable?
  
  **Disadvantages:**
  - High temperature >900°C
  - Low power density < 0.3 W/cm²
  - Degradation
  
  Round cells: simple sealing geometry
  Complex sealing geometry
  Low heating rates

- Anode supported with metallic interconnect
  
  **Advantages:**
  - High power density 1.0 W/cm²
  - Medium temperatures 700-800°C (pressurized operation)
  
  **Disadvantages:**
  - Degradation
  - Complex sealing geometry
  - Not red-ox stable
  - (Low heating rates)

- Light-weight APU

SOFC: Siemens Westinghouse Power Co
SOFC: Siemens Westinghouse Power Co

SOFC: Rolls Royce Fuel Cell Ltd
SOFC: HEXIS

SOFC: Versa Power Systems
Thanks for your attention

Questions anyone?