Water Recovery Schemes and Effects on the Water and Thermal Balances for a 100 kW PEMFC System
Introduction
Proton Exchange Membrane Fuel Cell

• **Benefits**
  – Low temperature (below 100 °C)
  – High energy density (1 kW/liter)

• **Applications**
  – Portable
  – Stationary
  – Automotive

• **Problems**
  – Water and thermal management
  – Infrastructure for the fuel supply
  – High cost
Introduction

Water and thermal management

- Stack cooling
- Intercooling and humidification
- Water recovery
- Fuel reforming
Introduction

Solution for the water and thermal management
– In portable applications
  Proper system control

– In automotive and stationary applications
  Several heat exchangers for the water recovery and the stack cooling.
Problem Statement

Various humidification schemes for PEMFCs
Problem Statement

• In automotive and stationary applications, the water recovery and the humidification are critical.
• There are several schemes to handle these.
• Appropriate schemes must match the system design.
Objectives

• Analysis of the water and thermal balance in a 100 kW PEMFC system
  – Condensation of water in the stack
  – Heat load in the heat exchangers
  – Water recovery

• Analysis of the influence of water recovery schemes on the water/thermal balance in the system
  – Comparison of water recovery scheme in the total heat load in the heat exchangers
Methodology

General PEMFC system

# Methodology

## Water recovery schemes

<table>
<thead>
<tr>
<th>System</th>
<th>Water for humidification</th>
<th>Water recovery device</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1</td>
<td>In gas phase</td>
<td>Water separator</td>
</tr>
<tr>
<td>System 2</td>
<td>In liquid phase</td>
<td>Condenser</td>
</tr>
</tbody>
</table>

[Image of Water separator and Condenser]
# Methodology

## Standard operating condition

<table>
<thead>
<tr>
<th>Stack overall</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output power from the stack $P_e$ (kW)</td>
<td>100 (Const.)</td>
</tr>
<tr>
<td>Unit cell voltage $V_c$ (V)</td>
<td>0.7 (Const.)</td>
</tr>
<tr>
<td>Operating pressure $P_{stack}$ (bar)</td>
<td>2</td>
</tr>
<tr>
<td>Operating temperature $T_{stack}$ ($^\circ$C)</td>
<td>80</td>
</tr>
<tr>
<td>Heat generation by the electrochemical reaction</td>
<td>Based on LHV</td>
</tr>
</tbody>
</table>

### Anode

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen usage</td>
<td>0.85</td>
</tr>
<tr>
<td>Relative humidity at the anode inlet (%)</td>
<td>100</td>
</tr>
</tbody>
</table>

### Cathode

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity at the cathode inlet $RH_{in}$ (%)</td>
<td>80</td>
</tr>
<tr>
<td>Stoichiometry at the cathode inlet $\lambda$</td>
<td>2</td>
</tr>
<tr>
<td>Mole fraction in the reactant air (dry)</td>
<td>Oxygen 0.21, Nitrogen 0.79</td>
</tr>
</tbody>
</table>
Results and Discussion

Water balance

Water recovery rate = \frac{\text{the mass of water for cathode humidification}}{\text{the mass of water in the cathode exhaust gas}}

![Graph showing the relationship between operating pressure and water recovery rate at different operating temperatures.]
Results and Discussion

Water balance

[Graph showing the relationship between operating pressure $P_{\text{stack}}$ (bar) and operating temperature $T_{\text{stack}}$ (°C) with relative humidity at the cathode exit labeled.]
Results and Discussion

Comments on the water balance

– At high temperature and low pressure, large amount of water must be recovered.
– However, the water flooding in the PEMFC stack is small there.
– Relative humidity at the cathode inlet can be low (around 60 %) to avoid water flooding in the PEMFC stack.
Results and Discussion

Thermal balance

System 1

System 2
Results and Discussion

Thermal balance

System 1  System 2

Total dissipation heat from the systems
Results and Discussion

Comments on the thermal balance

– General
  • Largest heat load is in the radiator.
  • Heat load in the radiator is increased with pressure due to water condensation in the stack.

– System 1 (scheme without phase change)
  • Heat load in the intercooler is increased with pressure.

– System 2 (scheme with phase change)
  • Heat load in the condenser is quite large at low pressure due to the water recovery.
  • Preheater is requested due to evaporation of the water for the humidification.
Results and Discussion

Comparison of the thermal balance

At low pressure and high temperature, dissipation heat from system 2 is quite large.

With increasing pressure, the deviation becomes small because the water recovery scheme has a minor effect.

\[
\text{Deviation} = \frac{(Q_{\text{system 1}} - Q_{\text{system 2}})}{Q_{\text{system 2}}}
\]
Summary

– At high temperature and low pressure, large amount of water must be recovered.

– The effect of water recovery scheme is large at such operating condition.
  • The scheme with phase change requests large heat dissipation in the condenser.

– With increasing pressure, the effect of the water recovery scheme becomes small because less requirement of water recovery.