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Potentials and Limits of Evaporative Cooling for Polymer Electrolyte Fuel Cells

Even though state-of-the-art polymer electrolyte fuel cells (PEFC) reach system efficiencies above 60 % [1], a substantial amount of heat has to be rejected to the environment. Conventional cooling approaches aim at transferring the waste heat to a liquid coolant that flows through dedicated cooling channels. This yields high heat fluxes from the cell to the coolant and ensures a uniform temperature distribution but requires a thick and complex design of bipolar plates [2]. As a novel concept, evaporative cooling does not require separate cooling channels and is therefore capable to reduce the fuel cell system volume, complexity and cost by up to 30 %. Additionally, the water evaporates close to the membrane and therefore contributes to a better humidification and thus higher ionic conductivity [3], which enables higher operating temperatures without the need for external humidification.

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Introduction

Potentials of Evaporated Cooling:

- Reduced stack and system volume due to simplified bipolar plates
- Higher operating temperatures without the need for external humidification

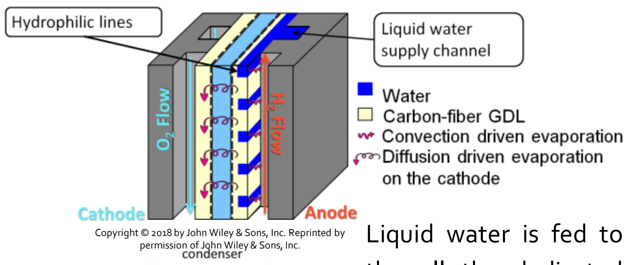
Open questions:

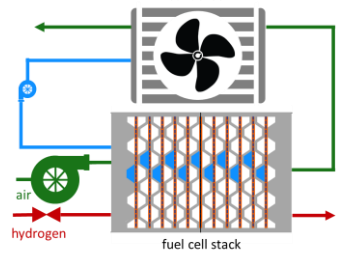
- Which operating conditions are suitable for evaporative cooling?
- How is the electrochemical performance affected by evaporative cooling?
- Is it possible to retain enough water from the exhaust gas to ensure a closed water loop?

Research approach:

In this work, a zero-dimensional fuel cell system model is developed. For each component, the **mass and energy balance** is solved. For the fuel cell stack, **electro-chemical equasions** are additionally taken into account.

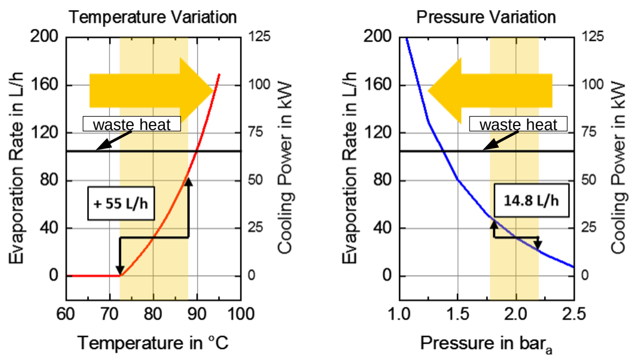
The PSI Evaporative Cooling Approach





Liquid water is fed to the cells thru dedicated water channels that are directly located in the anode flow-field. Subsequently, the water is wicked into a specially designed gas diffusion layer (GDL) with a mixed hydrophilic and hydrophobic pattern [4,5] and distributed through the entire cross-section. Consequently, the water evaporates, cools the cell by taking up the heat of evaporation and is released as water vapor.

Operating Conditions

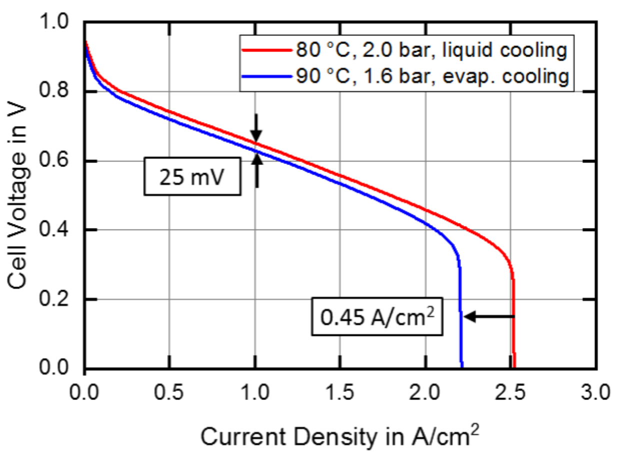


The evaporation rate and thus cooling power is a function of :

- operating temperature
- operating pressure
- stoichiometry

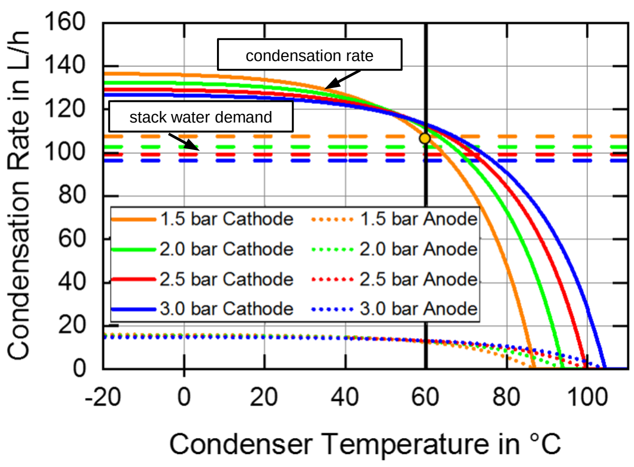
In order to provide sufficient cooling power, it is necessary to operate an evaporatively cooled fuel cell at **increased operating temperature** or **decreased operating pressure.**

Electrochemical Performance



Simulation results show that operating conditions which are favorable for evaporative cooling (i.e. 90 °C, 1.6 bar) show a slightly decreased electrochemical performance compared to conventional operating conditions (80 °C and 2 bar)

Closed Water Loop



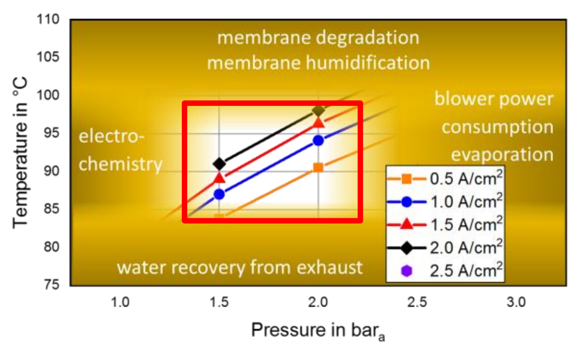
Ideal condensation rate increases with decreasing condenser outlet temperature. Intersection with stack water demand yields necessary condenser outlet temperature (e.g. 60 °C in above example).

→ Closed water loop is possible over a wide variety of operating conditions

Summary

- Reduced stack and system volume up to 35 %
- Increased operating temperature w/o external humidification
- Evaporation rate and thus cooling power is a function of pressure, temperature and stoichiometry
- Operating conditions favorable for evaporation are electrochemically slightly inferior
- Closed water loop is possible under wide variety of operating conditions

Proposed operating window for evaporative cooling:



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