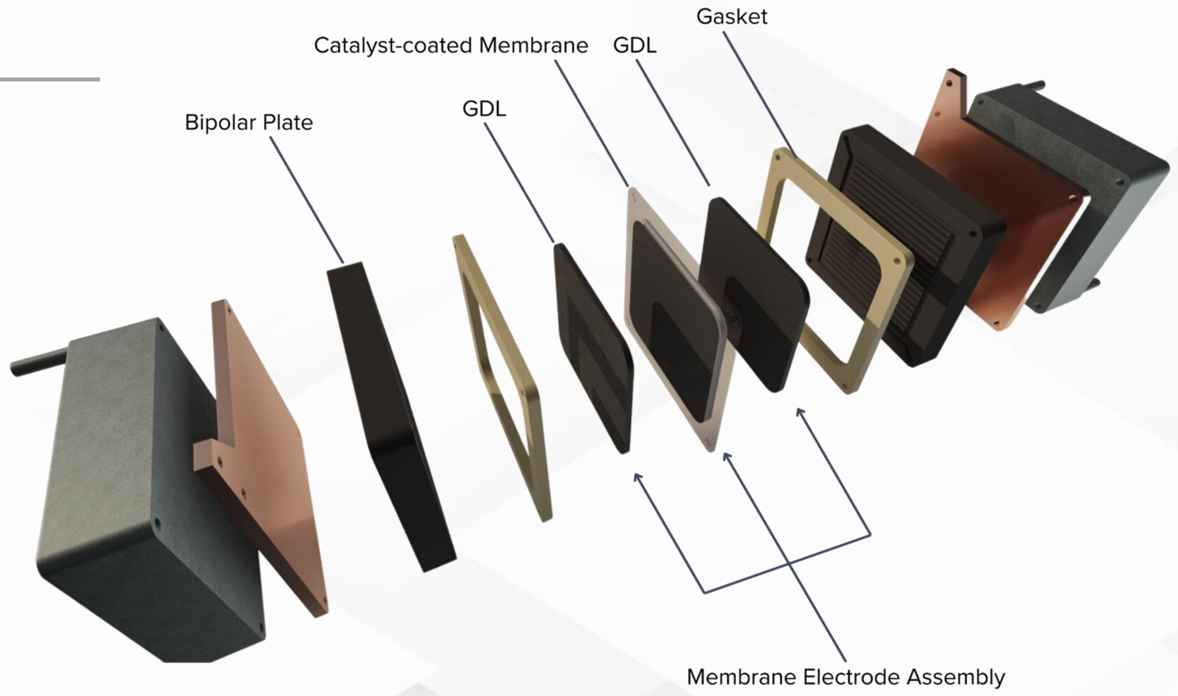
Advanced Thermal Management Strategies for PEM Fuel Cells using Phase Change Materials

Darlene Pudolin, CAPLINQ Corporation

3–5 December 2024| Stuttgart, Germany

Fuel Cells

Introduction

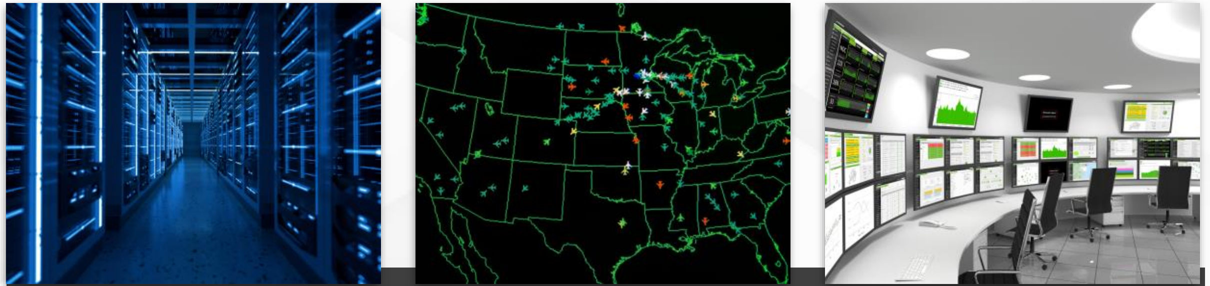


Fuel Cell

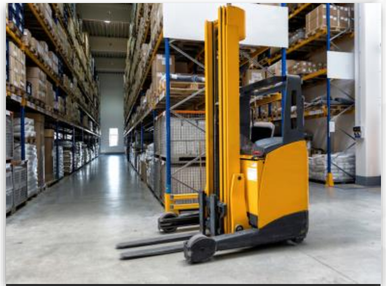
Electrochemical device that generates electricity **without combustion** by combining hydrogen and oxygen in an electrochemical reaction, producing only water and heat as by-products.

Fuel cells **power a range of applications today**, from homes and critical facilities to vehicles like cars, buses, and trains, offering a clean, efficient energy source.

Backup Power



Prime Power for Critical Loads

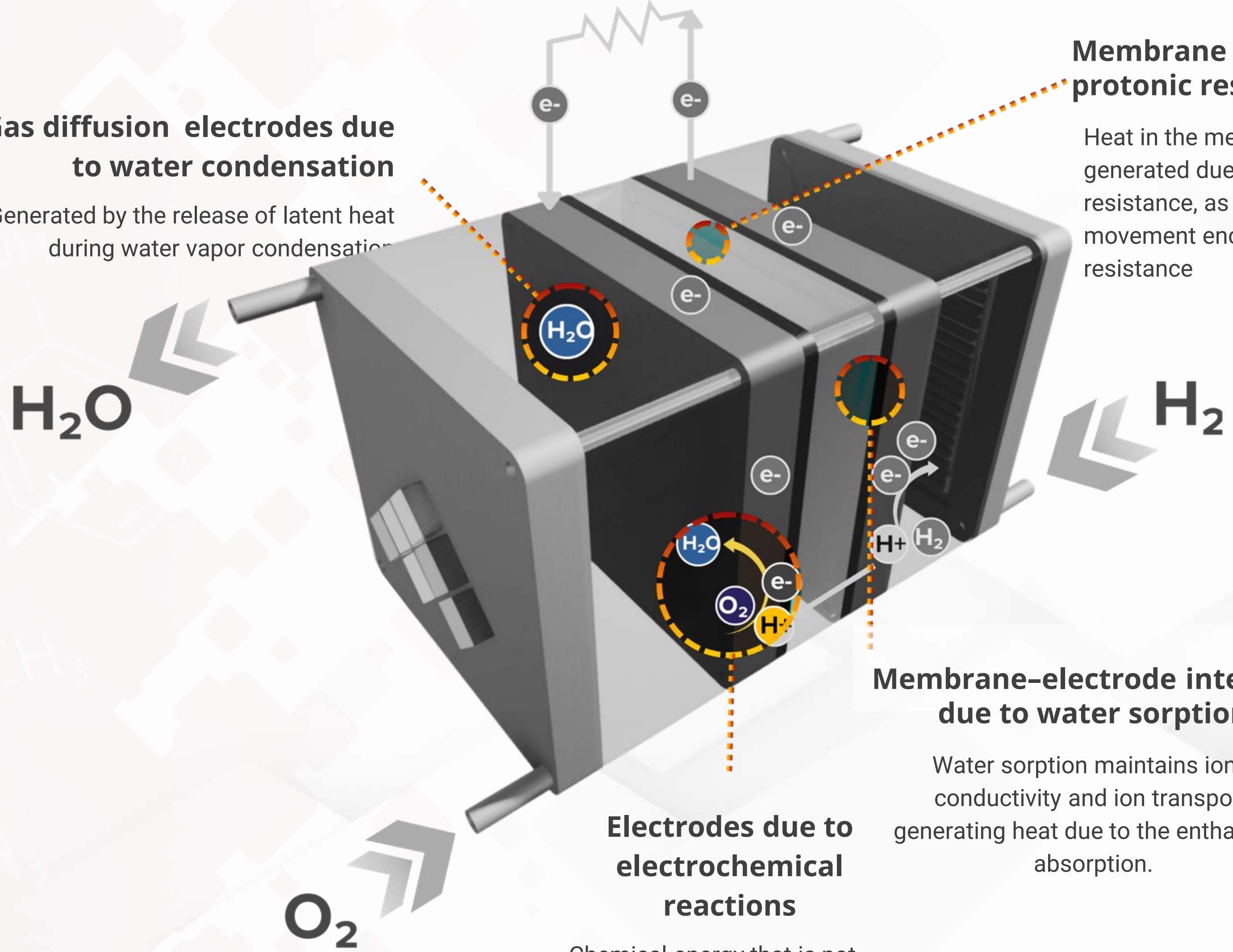


Specialty Vehicles

Transportation

Heat Generation in Fuel Cells

Introduction



Gas diffusion electrodes due to water condensation

Generated by the release of latent heat during water vapor condensation

Membrane due to protonic resistance

Heat in the membrane is generated due to protonic resistance, as ion movement encounters resistance

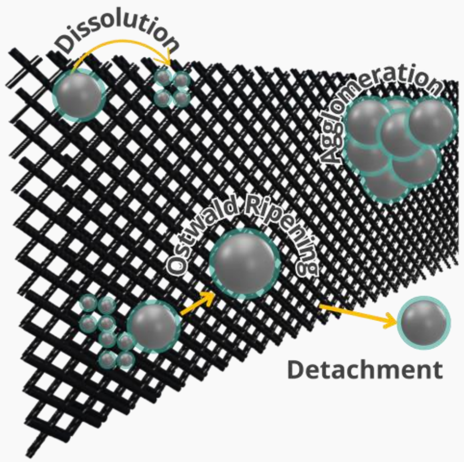
Membrane–electrode interface due to water sorption

Water sorption maintains ionic conductivity and ion transport, generating heat due to the enthalpy of absorption.

Electrodes due to electrochemical reactions

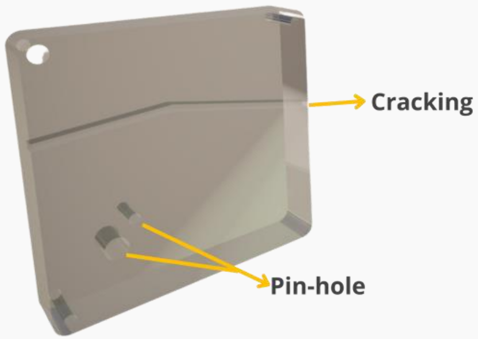
Chemical energy that is not converted into electricity is released as heat

High-temperature operation and **localized hot spot formation** are two major sources of **material degradation**.



Catalyst layer and GDL degradation

through dissolution, agglomeration, detachment, and Ostwald ripening, with carbon support corrosion adding to these issues. Higher temperatures increase these degradation rates.



Membrane dehydration

increases the risk of physical damage, such as cracking or pin-hole formation. High temperatures can increase ohmic losses. Ionomers can degrade too.

caplinq

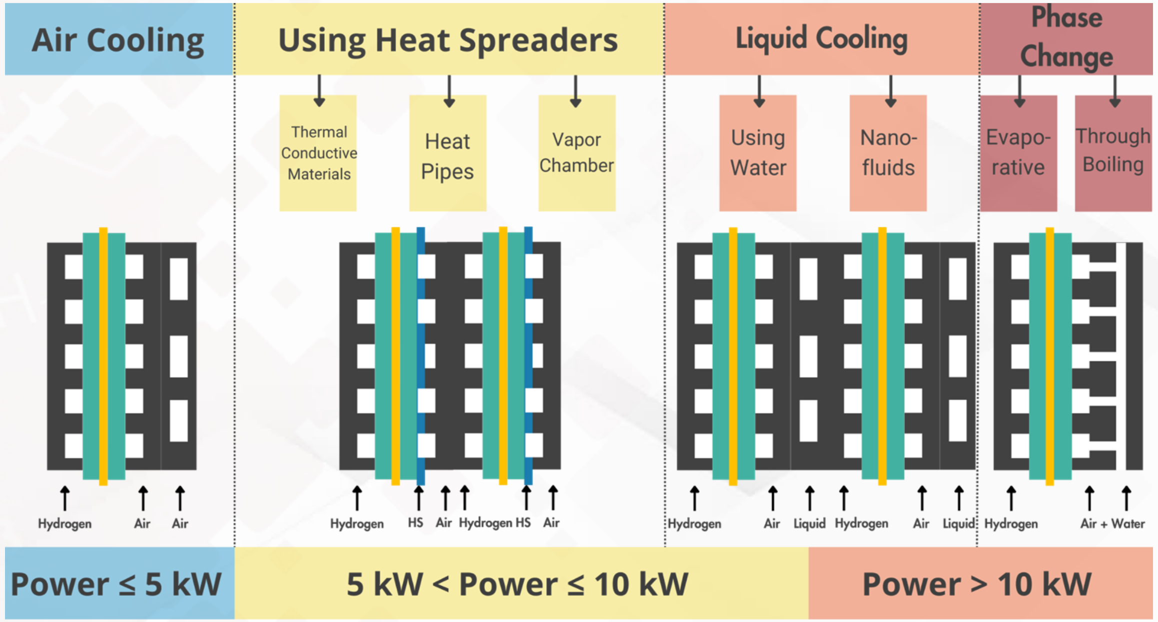
Thermal Management Strategies in PEM Fuel Cells

Introduction

Cooling Methods for PEM Fuel Cells

Heat/thermal management of the PEMFC is normally achieved via employing a suitable **cooling strategy depending on the power and application of the stack**.

- For **low-power fuel cells (<2 kW)**, inexpensive air cooling systems that decrease the system complexity are adopted.
- For **more powerful fuel cells**, such as large vehicles generating more heat, liquid cooling systems can be considered as a logical choice.



Phase Change Materials

used in latent heat thermal energy storage systems since they can store large amounts of energy without significantly deviating from their melting point

storing thermal energy during the charging (or melting) phase of the phase transition process and releasing it during the discharging phase (freezing)

Ideal Properties of a Phase Change Material for High-power Fuel Cells

- Appropriate phase change temperature
- High latent heat
- High thermal conductivity in both liquid and solid phases for higher heat transfer rate
- High specific heat capacity

Despite their potential, **the integration of phase change materials to improve the thermal management and overall efficiency of PEMFCs remains largely unexplored** in both research and commercial applications. This gap highlights an opportunity for innovation.

PCM Integration in PEMFC Cooling Channels

Related Study

International Journal of
Energy Research

Research Article

Thermal Management Analysis of Proton Exchange Membrane Fuel Cell Filled with Phase Change Material in Cooling Channel

Wanteng Wang, Nan Li, Jinhui Zhang, Caihong Zhang, Liang Zhang
School of Vehicle and Energy, Yanshan University, Qinhuangdao 066004, China

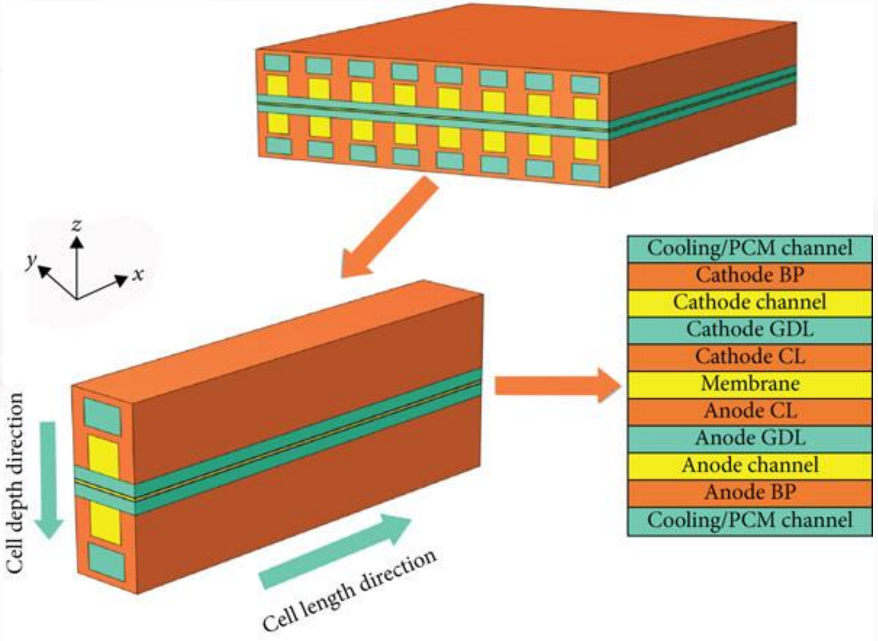
Received 14 November 2022; Revised 5 March 2023; Accepted 9 March 2023; Published 30 March 202
https://doi.org/10.1155/2023/9077046

PCMs have been extensively applied in the thermal management of Li-ion batteries. However, they have not been extensively used in the thermal management of PEMFCs.

- **Objective:** Proposed passive thermal management using PCM for improved PEMFC thermal control
- **Model:** Developed a **3D, nonisothermal PEMFC model** with air-cooled (ACC) and PCM cooling channels (PCC)
- **Analysis:** Evaluated PEMFC performance across cooling channels, focusing on reactant/product concentration, temperature distribution, membrane conductivity, and current density.

PEMFC Model

Wang, Wanteng, Li, Nan, Zhang, Jinhui, Zhang, Caihong, Zhang, Liang, Thermal Management Analysis of Proton Exchange Membrane Fuel Cell Filled with Phase Change Material in Cooling Channel, *International Journal of Energy Research*, 2023, 9077046, 12 pages, 2023. https://doi.org/10.1155/2023/9077046



PEMFC Dimensions

Geometric parameter	Value
Cell length/width (mm)	7.2/1.2
BP thickness (mm)	0.12
Rib width (mm)	0.3
Channel height/width (mm)	0.6/0.6
ACC/PCC height/width (mm)	0.4/0.72
GDL/CL thickness (mm)	0.2/0.012
Membrane thickness (mm)	0.05
GDL/CL porosity	0.4

PCM Integration in PEMFC Cooling Channels

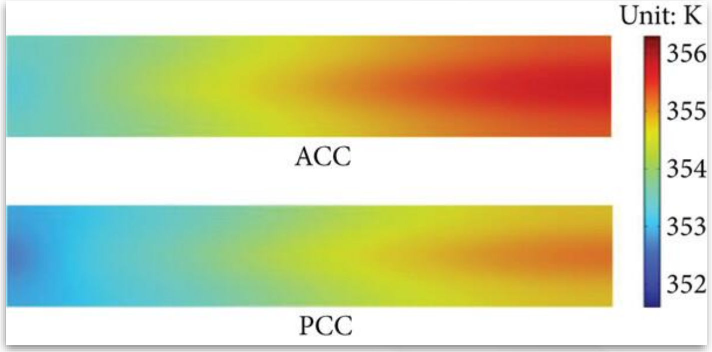
Related Study Methodology and Results

Governing Equations	
Continuity Equation	$\nabla\cdot\left(\varepsilon\rho\vec{u}\right) = S_m$
Momentum Equation	$\frac{\partial(\varepsilon\rho c_p)}{\partial t} + \nabla\cdot\left(\varepsilon\rho c_p\vec{u}T\right) = \nabla\cdot\left(k^{eff}\nabla T\right) + S_Q$
Energy Equation	$\nabla\cdot\left(\varepsilon\rho\vec{u}\vec{u}\right) = -\varepsilon\nabla p + \nabla\cdot\left(\varepsilon\mu\nabla\vec{u}\right) + S_u$
Species Transport Equation	$\frac{\partial\left(\varepsilon C_k\vec{u}\right)}{\partial t} + \nabla\cdot\left(\varepsilon\vec{u}C_k\right) = \nabla\cdot\left(D_k^{eff}C_k\right) + S_k$
Electron and Proton Transport Equations	$\nabla\cdot(\sigma_{sol}\nabla\varphi_{sol}) + S_{sol} = 0,$ $\nabla\cdot(\sigma_{mem}\nabla\varphi_{mem}) + S_{mem} = 0,$
Electrochemical Equations	$j_{an} = Aj_{ref,an}\left(\frac{C_{H_2}}{C_{H_2}^{ref}}\right)^{\gamma_{an}}\left[\exp\left(\frac{\alpha_{an}}{RT}F\eta_{an}\right) - \exp\left(-\frac{\alpha_{cath}}{RT}F\eta_{an}\right)\right]$

Boundary Conditions

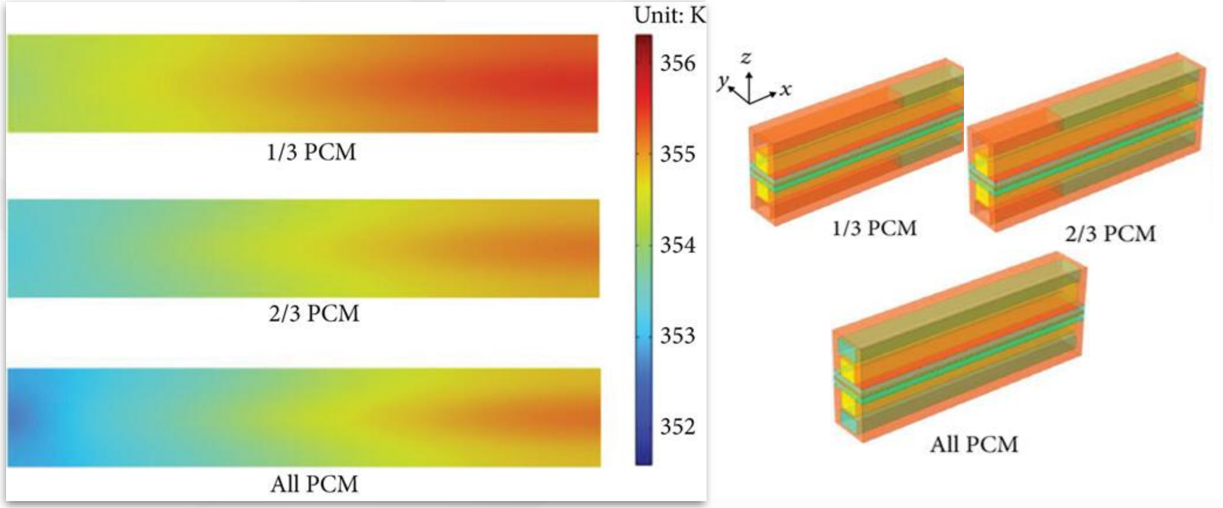
- Stable operation of the PEMFC
- Laminar gas flow in the channel
- Ideal gases assumption for channel gases
- Homogeneous and isotropic PEM, CL, and GDL

Temperature analysis ACC and PCC



Reference Results:
Temperature distribution showed only a 2 °C difference.

Temperature and performance analysis of fillings of different contents of PCM



PCM Integration in PEMFC Cooling Channels

Study Methodology and Objectives

- **Objective:** Propose passive thermal management using a **commercial PCM** for improved PEMFC thermal control
- **Model:** Develop a **nonisothermal PEMFC model** with air-cooled (ACC) and PCM cooling channels (PCC) using MATLAB software
- **Analysis:** Evaluated PEMFC performance across cooling channels, focusing on temperature distribution, membrane conductivity, and water molar fraction.

Physical parameters of the PCM

Property	Sodium acetate trihydrate*	Honeywell PTM6000
Melting Temperature [K]	331.15	**318.15**
Thermal Conductivity [W/m· K]	0.6	**6.0**
Specific Capacity [kJ/kg· K]	2.9	**0.97**

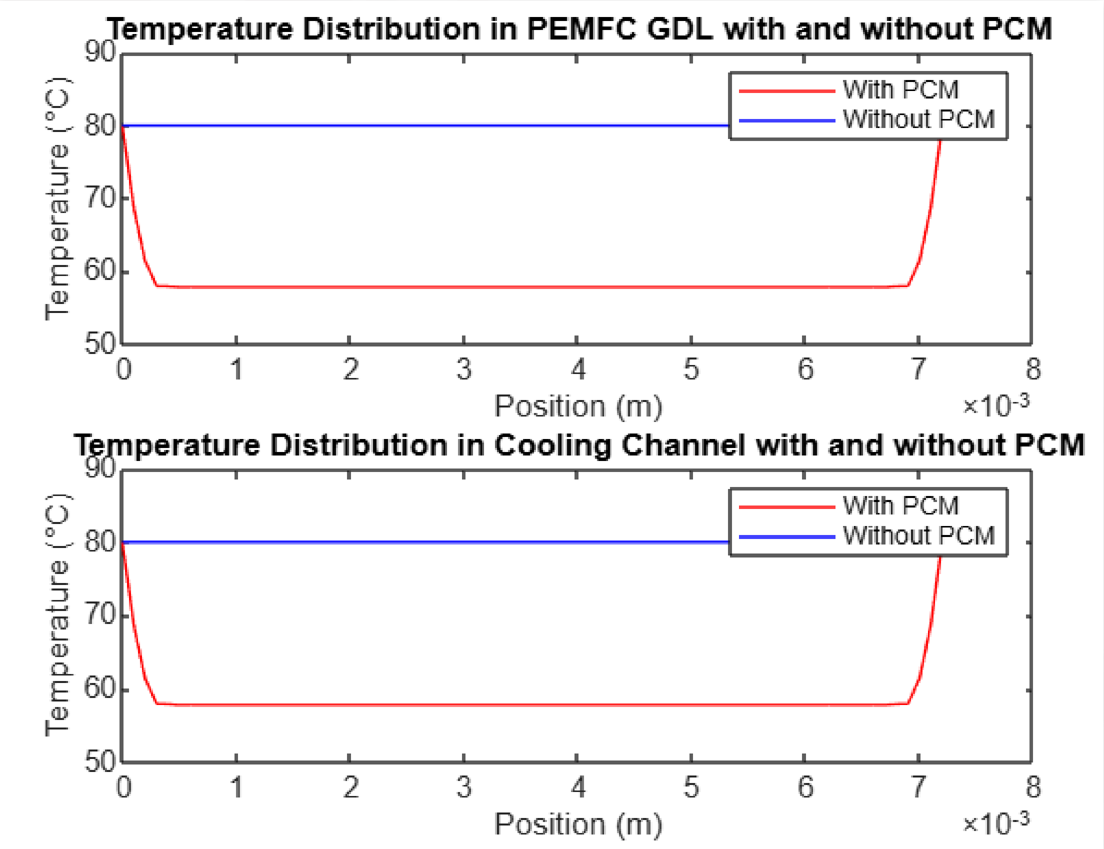
***from a reference study**

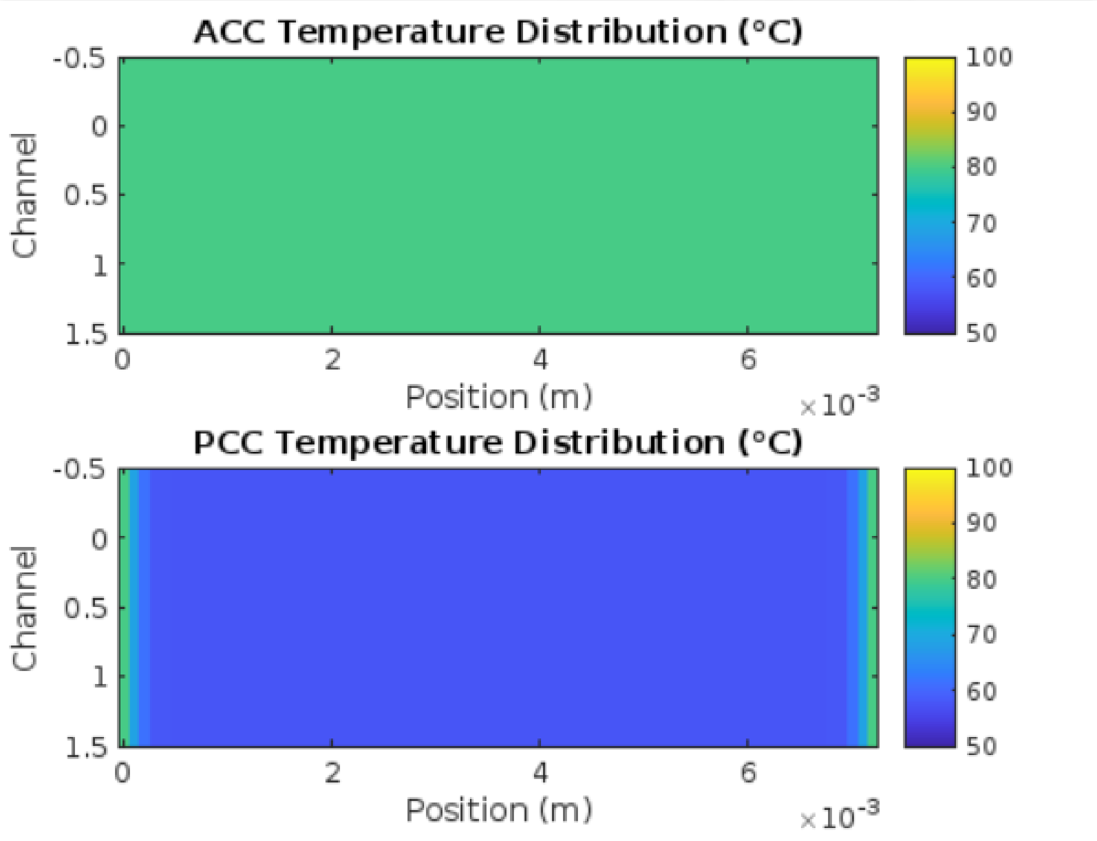
Parameters and Boundary Conditions

Parameter	Value	Parameter	Value
GDL/CL electrical conductivity (S·m-1)	5000/4000	Cathode/anode concentration dependence	1/1
Cathode/anode stoichiometry	3/0.5	Cathode/anode reference exchange current density (A·m-2)	1000/100
BP thermal conductivity (W·m-1·K-1)	22.5	Cathode/anode reference concentration (mol·m-3)	56.4/3.39
GDL/CL thermal conductivity (W·m-1·K-1)	3/1	Cathode/anode relative humidity	85%/100%
Open-circuit voltage (V)	1	*H_2 reference diffusivity* (m2·s-1)	9.15 × 10−5
Operating temperature (K)	333.15	*O_2 reference diffusivity* (m2·s-1)	3.23 × 10-5
Reference pressure (Pa)	101325	*H_2O reference diffusivity* (m2·s-1)	7.35 × 10-5
Cathode/anode transfer coefficient	1/0.5		

PCM Integration in PEMFC Cooling Channels

Initial MATLAB Simulations

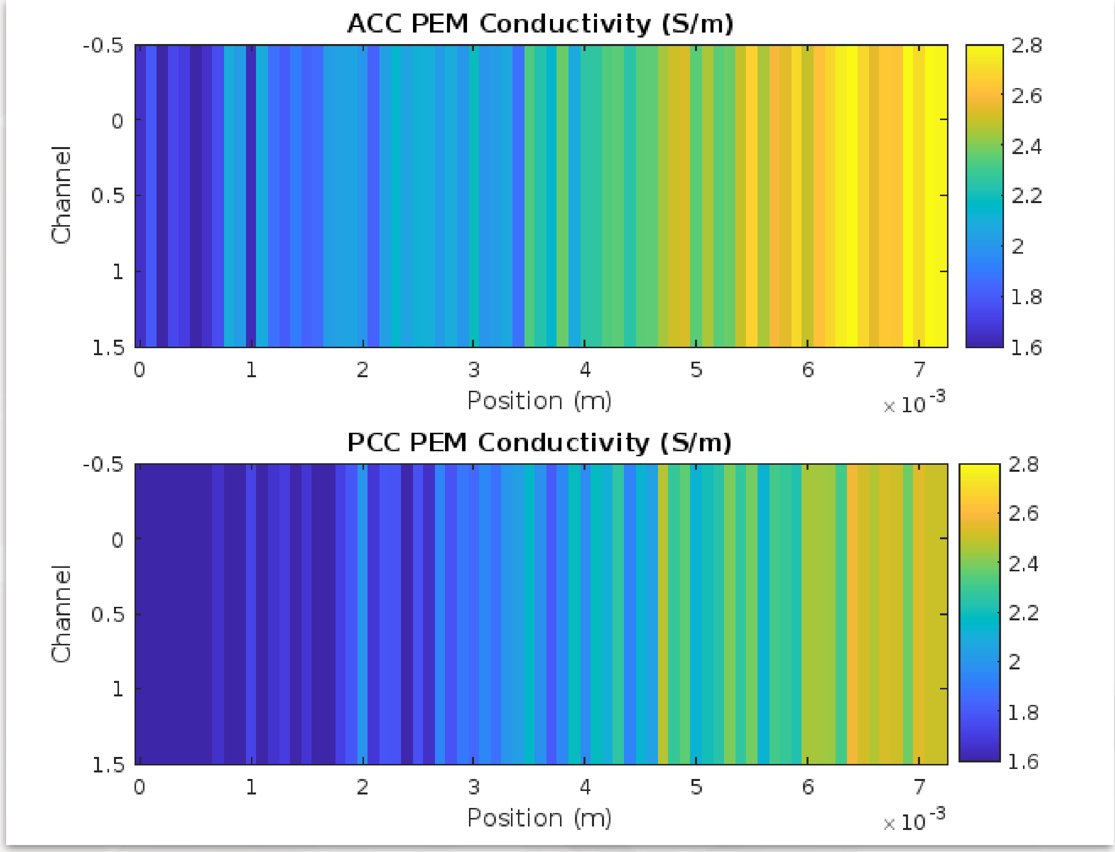


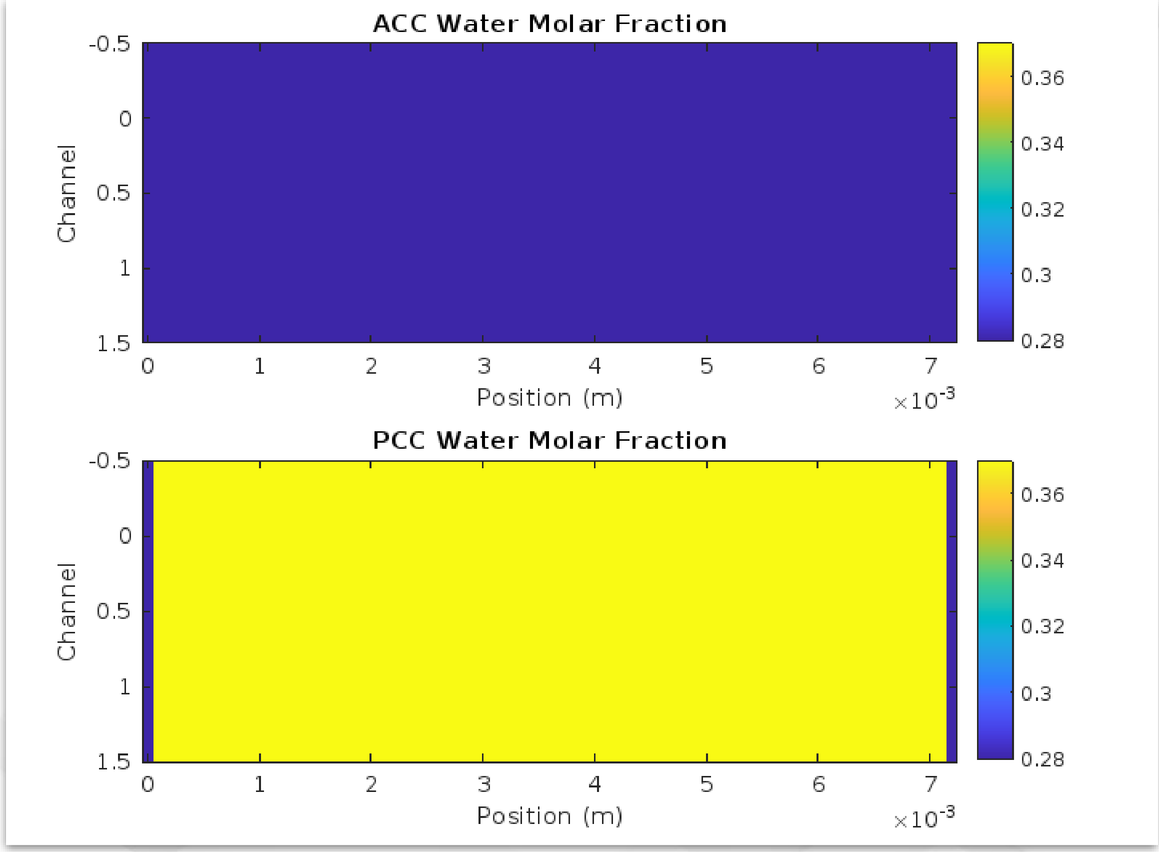


The GDL–CL interface temperature is 80 °C without PCM. It drops to 60 °C when Honeywell PTM6000 PCM is applied, equivalent to a **20 °C reduction**.

PCM Integration in PEMFC Cooling Channels

Initial MATLAB Simulations





The integration of PCM leads to a noticeable increase in water molar fraction, with values ranging from 0.28 to 0.37. This increase is due to the enhanced condensation effect induced by the PCM, which stabilizes the temperature and promotes moisture retention. The PCM's ability to absorb heat and maintain lower temperatures results in higher moisture levels, which can significantly benefit the hydration of the PEM, potentially improving the fuel cell's efficiency and lifespan.

PCM Integration in PEMFC Cooling Channels

Conclusion

Temperature Stabilization

A significant temperature reduction of nearly 20°C at the GDL-CL (Gas Diffusion Layer–Catalyst Layer) interface when PCM is integrated.

Enhanced Water Retention

The PCM stabilizes temperature and enhances water condensation within the cooling channel. Hydration plays a critical role in maintaining high proton conductivity, as it reduces ohmic losses and promotes efficient ion transport.

Conductivity Impact

Lower operating temperatures and improved moisture retention lead to a more stable and conductive PEMFC. This enhances the overall performance and efficiency of the fuel cell. By mitigating thermal cycling and dehydration risks, the PCM contributes to prolonging the lifespan of the PEM.

Commercial Potential

The simulations indicate that integrating advanced PCM technologies can significantly improve the thermal management of PEMFCs. This has both research and commercial implications for optimizing fuel cell designs.

GET IN TOUCH

Contact us to find out how CAPLINQ can help your company reach the next level

Amsterdam, Netherlands Office
Serving Europe, Middle East, India, Asia & Africa

CAPLINQ Europe BV
Industrieweg 15E
1566JN Assendelft
The Netherlands

Phone: +31 (20) 893 2224
Fax: +31 (84) 746 3497

Detroit, USA Office
Serving USA, Mexico & South America

CAPLINQ Americas, Inc.
36927 Schoolcraft Rd
Livonia, MI 48150
USA

Phone: +1 (313) 558-8243
Fax: +1 (702) 995-1235

Ottawa, Canada Office
Serving Canada

CAPLINQ Corporation
80 Sirocco Crescent
Ottawa, ON, K2S 2C9
Canada

Phone: +1 (613) 482-2215
Fax: +1 (702) 995-1235

ASEAN Office
Serving South East Asia

CAPLINQ Malaysia Sdn. Bhd.
S-08-07, Persiaran Kelicap Setia Triangle
11900 Bayan Lepas, Penang
Malaysia

Phone: +60 (12) 430 2223

Philippines Office
Serving Philippines

CAPLINQ Philippines, Inc.
Unit 611 & 612 Civic Prime Bldg.
2501 Civic Drive, Filinvest City
Alabang, Muntinlupa
1781 Metro Manila, Philippines

Phone: +63 939 919 2437

GLOBAL SALES & APPLICATIONS SUPPORT

Email: sales@caplinq.com
Website: www.caplinq.com

Facebook: Find us at Facebook.com/caplinq

X: Follow us at x.com/caplinq

Email us at info@caplinq.com