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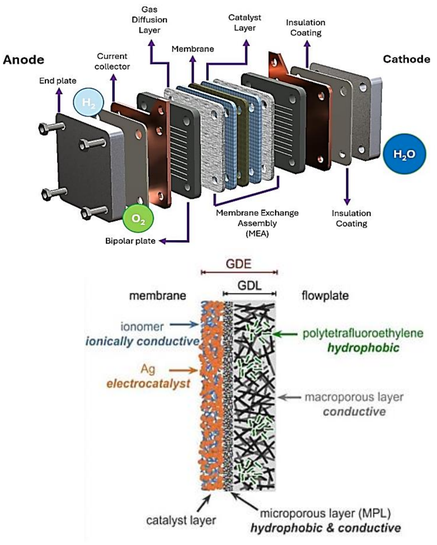
POROUS MEDIA CHARACTERIZATION FOR FUEL CELL OPTIMIZATION: A MESOSCOPIC APPROACH VIA LATTICE BOLTZMANN METHOD

INTRODUCTION

- Polymer Electrolyte Fuel Cells (PEFCs) are promising devices for clean energy generation.
- Performance strongly depends on porous media components: Gas Diffusion Layer (GDL) and Catalyst Layer (CL).
- Transport phenomena inside porous structures are difficult to analyze experimentally.
- The Lattice Boltzmann Method (LBM) provides a mesoscopic framework for analyzing these processes.

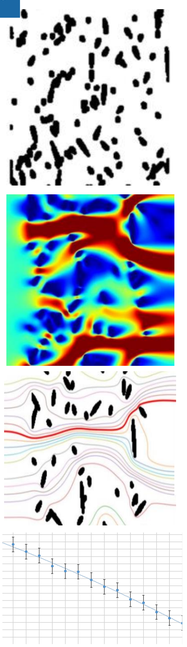


OBJECTIVE

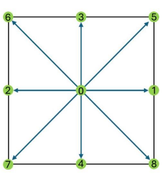
This study examines recent developments in the application of the Lattice Boltzmann Method (LBM) to porous media analysiss and optimization in Polymer Electrolyte Fuel Cells (PEFCs).

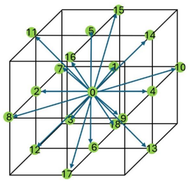
METHODOLOGY

Porous Structure → LBM Simulation → Transport Analysis → Performance Optimization



LBM





$$\frac{\partial f(r,t)}{\partial t} + c \cdot \nabla f(r,t) = \Omega$$

$$\frac{\partial f_k(r,t)}{\partial t} + c_k \nabla f_k(r,t) = \frac{1}{\tau}\left[f_k^{eq}(r,t) - f_k(r,t)\right]$$

$$f_k^{eq}(r,t) = \omega_k \rho \left[1 + \frac{c_k u_k(r,t)}{{c_s}^2} + \frac{(c_k u_k(r,t))^2}{2{c_s}^4} - \frac{(u_k(r,t))^2}{2{c_s}^2}\right]$$

$$u(r,t) = \frac{\sum_k f_k c_k(r,t)}{\rho(r,t)} \qquad \rho(r,t) = \sum_k f_k$$

- **Period**
  - 2005-2025
- **Database**
  - Scopus
- **Keywords**
  - Lattice Boltzmann Method
  - PEFC
  - Porous Media
  - Optimization
- **Criteria**
  - Articles
  - Reviews
  - Book chapters

MAIN FINDINGS

Water Management Optimization.

- Wettability engineering improves water removal.
- Hydrophobic surfaces reduce flooding.
- Hydrophilic gradients improve drainage.
- LBM predicts water accumulation and droplet behavior.

Gas Diffusion Layer Optimization.

- Porosity strongly affects transport.
- Pore size distribution impacts diffusivity.
- Fiber orientation modifies permeability.
- Compression changes mass transport properties.

Multiscale Modeling.

- LBM can be coupled with:
  - Stochastic models.
  - Continuum models.
  - Catalyst layer simulations.
- Hybrid models reduce computational cost.

Key Contributions of LBM.

- Water Management.
- Structural Optimization.
- Multiphase Modeling.
- Multiscale Analysis.
- Fuel Cell Design Optimization.

CONCLUSIONS

- LBM is a powerful tool for porous media characterization.
- Water transport remains one of the most critical challenges in PEFCs.
- Microstructural optimization of GDLs significantly improves performance.
- Hybrid LBM approaches are emerging as a promising research direction.
- LBM bridges experimental observations and computational predictions.

FUTURE RESEARCH

Future Perspectives.

- AI-assisted porous media design.
- Digital twins for fuel cells.
- Generative design of GDL structures.
- Coupling LBM with Machine Learning.
- Real-time optimization of PEFC operation.