Popular science abstract

„ Enhancing the energy efficiency of DFAFC stacks - mathematical modeling and experimental validation using 3D printing”

Fuel cells are electrochemical devices that convert the chemical energy of fuel into electricity and heat through the spatial separation of oxidation and reduction reactions, achieved by placing an electrolyte (e.g., an ion-conducting membrane) between the anode and cathode. Due to the high efficiency of single-step energy conversion and zero or low CO_2 emissions, fuel cells will significantly contribute to achieving emission neutrality by 2050 and becoming independent from depleting fossil fuel resources. These devices can be fed by gaseous fuels such as hydrogen, producing only water, or liquid fuels obtained using renewable energy and carbon dioxide, ensuring the emission neutrality of the fuel cell.

A particularly interesting fuel is formic acid, which, in concentrations used in the fuel cell, is environmentally safe, non-flammable, and, as a liquid, easy to implement into the current fuel infrastructure. This would reduce fuel distribution costs to users and contribute to the dissemination of fuel cell technology. However, the transport conditions of reagents are more challenging in formic acid fuel cells (DFAFCs) than in hydrogen-fed fuel cells due to the lower diffusivity of the liquid. Therefore, the intensification of mass transport and effective distribution of reactants in the DFAFC stack becomes crucial for improving their performance.

The aim of this project is to increase the energy efficiency of DFAFC stacks by developing an efficient and uniform reactant distribution system using manifolds (channels between bipolar plates), characterised by a low flow drag coefficient. To achieve this goal, mathematical modelling of DFAFC operation will be used, enabling the design of an effective system for the continuous removal of the gaseous product of the anodic reaction, which is carbon dioxide, as it unfavourably increases flow resistance in the system and blocks fuel access to the reaction zone.

The mathematical modelling of DFAFC operation will be integrated with computational fluid dynamics, allowing for virtual experiments. In the next stage, these will be experimentally verified through the analysis of two-phase flow on the anode side in a transparent fuel cell constructed using 3D printing with photocurable resin. This cell will also undergo current-voltage characterisation. The computational model will be used to evaluate the effectiveness of gas removal systems and reactant distribution systems in the DFAFC stack. Simulations will include multiphase flow and describe the kinetics of formic acid oxidation and oxygen reduction reactions. The developed model will be used to determine the current-voltage characteristics of the fuel cell under different process conditions. The next research stage will combine the selected gas removal system with the newly designed reactant delivery system in the DFAFC stack. The final stage will involve the electrochemical analysis of DFAFC stacks with the proposed geometries of the reactant distribution and carbon dioxide removal systems.

The project will result in the development of a mathematical model of a DFAFC combined with computational fluid dynamics, enabling simultaneous analysis of many process parameters, optimisation of system geometries, and reduction of laboratory research costs by decreasing the number of experiments. The project will develop a system for the uniform distribution of reactants in the DFAFC stack. This system will reduce pressure drop and increase the energy efficiency of the device. The project results will also enrich the research area on efficient reactant distribution in fuel cells fed by liquid fuels. Improving this technology will accelerate the implementation and dissemination of fuel cells due to the significantly easier storage and transport of liquid fuel, contributing to the faster development of technology conducive to achieving emission neutrality by 2050.