Study of the influence of microstructure on reactive flow process in open-porous components for high-temperature fuel cells

In the 21st century human society is becoming more and more aware of its influence on the natural environment. One of the aspects of the growing population is the pollution, which needs to be significantly reduced. Especially, the air pollution caused by the industry, transportation or energy generation. Hence, the development of new, green types of energy sources is of great importance. It can be achieved in two ways: by the utilization of renewable energy sources or by adopting pollution-free utilization of the currently used energy sources like coal or gas. One of potential solution for the latter are fuel cells, which are electrochemical devices generating electrical energy by converting fuel (i.e. hydrogen, hydrocarbons) into water. Therefore, zero or near zero net greenhouse gas emission can be achieved. Additionally, the energy conversion rate, depending on fuel cell type, is in range of 40-60% which is higher than conventional energy sources.
Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC) can be classified as high-temperature fuel cells, working in temperatures above 600^{o}C. Such an operating temperature is high enough for thermal decomposition of hydrocarbons and consequently internal fuel reforming. Hence, high-temperature fuel cells are more fuel flexible and can be directly fed with other fuels than hydrogen, in example various hydrocarbons (methane, biomass, alcohols etc.) or even gasified coal. The high temperature is also important when the fuel cells are considered, not only as an electricity source but also as a heat source for household/industrial heating or additional power generation, e.g. using heat recovery steam generators. Cogeneration enables to increase the efficiency of the Combined Heat & Power (CHP) systems with high-temperature fuel cells even to 90%. Both technologies are at commercialization step, but operational efficiency of the devices available in the market is far from this which is predicted theoretically. This is mainly due to materials issues, which has not been fully solved for last 20 years. During this time a lot of experiments have been performed basing on the intuitive approach rather than deep understanding of the processes taking place in the cell.
However, the latest discovery of our research group revealed that the efficiency of the MCFC can be doubled solely by manipulating the porous microstructure of the electrode. That finding needs a scientific clarification, so the electrodes' material could be deliberately optimized. One of possible explanations are interpenetrating transport paths for ions and gaseous reagents. Therefore, the study of the reactive flow inside materials' structure is of great importance to fully elucidate phenomena taking place in electrodes during operation.
The scientific goal of this project is to determine the influence of the microstructure on the reactive flow process in open-porous electrodes for high-temperature fuel cells. The main research hypothesis is that electrode material's structure influence the mass transport process and reaction kinetics in high-temperature fuel cells. Porous structure parameters like porosity, mean pore size or tortuosity can significantly influence the material's permeability. Hence, it can influence directly the delivery of the reactants to the reaction zone and removal of the reaction products from this region, and indirectly the overall reaction kinetics. A better understanding of these phenomena is necessary for the development of more efficient high-temperature fuel cells.
Project's objective will be accomplished by combination of fabrication and characterization of the real materials with advanced modeling studies. During project realization, electrodes for molten carbonate fuel cell will be fabricated via a tape casting method with subsequent firing process. Characterization of the samples will be performed using scanning electron microscopy and x-ray microtomography. Quantitative image analysis of the obtained 3D images from tomographic data will be executed and the results will serve as an input for generation and validation of representative models of the microstructure. Afterwards, fabricated and new materials scenarios with different porous structure parameters will be generated and reactive flows will be calculated by using finite volume method approach. The results will be benchmarked with current/voltage characteristics of the fuel cell assembly evaluated in working conditions in a testing rig.