## 1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

***Project title:*** *Ionic liquid based Hybrid ElectRolyte Membranes for proton conducting fuEl cellS (HERMES)*

1.1Project goals

The main goal of this project is to overcome one of the key limitations of proton exchange membrane fuel cells, namely water management combined with the improved electrochemical performance. The new advanced polymer membranes (stable over a wide temperature range) will be elaborated by the incorporation and immobilization of the ionic liquids inside the polymer matrix. The different ways of the membrane preparation (e.g. by electrospinning or solvent evaporation) will be studied. The obtained membranes will be characterized from the material point of view (utilizing e.g. TEM, SEM, AFM, contact angle measurements, zeta potential, mechanical stability). Subsequently, the proton conductivity, fuel cell power density, and transport properties will be determined. Moreover, the influence of the following factors, i.e. the type of ionic liquid (hydrophilic, hydrophobic), the mode and conditions of membrane preparation, will be taken into account.

1.2. Outline

Fuel cells allow converting the energy of the chemical reaction between the fuel and the oxidant into the electrical energy. Proton Exchange Membrane Fuel Cell (PEMFC) is an example of the commonly studied fuel cell possessing Proton Exchange Membrane (PEM) as the electrolyte. PEM is the key component of the fuel cell, responsible for transport of protons through the polymeric membrane from anode to cathode that enables efficient operation of PEMFC.

However, PEMFC has not been used on the industrial scale so far, due to its several disadvantages, such as: high cost, which is contingent upon the price of commonly used Nafion® membrane, problems with water management related with membrane sensitivity to drying and moisture, high transport of water, and the requirement for the exploitation of the expensive catalysts. Furthermore, the currently exploited Nafion® membrane in PEMFC displays the significant drop of its efficiency during the operation of fuel cell above 80°C, which is related to the excessive water evaporation from the membrane. PEMFC working at the low temperature demonstrates also the sever sensitivity of anode to impurities, which requires the usage of highly pure hydrogen.

To obtain PEMs applied at higher temperatures under non-humidified conditions, ionic liquids (ILs) can be used as proton carriers in PEMs based on the non-fluorinated polymers. The effects of polymer blending, crosslinking and the incorporation of inorganic particles on the membrane properties and fuel cell performance will be investigated. The incorporation of inorganic particles modified with ILs might also be an effective approach to design high-performance PEMs for HT-PEMFC. In order to reduce the costs of the PEMFC a search for modifying the currently used proton exchange membranes (PEM) and method of novel polymeric material elaboration (e.g. mixed matrix membranes – MMMs possessing inorganic fillers or polymer inclusion membranes – PIMs containing ionic liquids) will be conducted. Due to the unique properties of ionic liquids, such as good thermal stability, high ionic conductivity, negligible vapor pressure, non-flammability, electrochemical stability, ionic liquids will be used as the promising and efficient additive for polymeric membrane materials enabling to change and tailor the properties of the membranes. The new advanced polymer membranes (stable over a wide temperature range) will be elaborated by the incorporation and immobilization of the ionic liquids inside the polymer matrix.

1.3. Work plan

- preparation of the pristine and ILs containing polymeric membranes various materials, using electrospinning or phase inversion induced by a solvent evaporation methods.

- modification of the membrane material using various types of ionic liquids and nanofillers.
- material characterization of membranes with the implementation of various analytical methods, (scanning electron microscopy, transmission electron microscopy, atomic force microscopy, infrared and Raman spectroscopy, impedance spectroscopy, and thermogravimetric analysis.
- investigation of the electrochemical properties of the obtained membranes - the efficiency and durability of the ILs containing membranes will be evaluated during the operation of designed PEMFC. The performance of the PEMFC will be testified based on the current-voltage characteristics.

**1.4. Literature**


1. Fatyeyeva, K.; Rogalsky, S.; Makhno, S.; Tarasyuk, O.; Soto Puente, J.A.; Marais, S. Polyimide/Ionic Liquid Composite Membranes for Middle and High Temperature Fuel Cell Application: Water Sorption Behavior and Proton Conductivity. Membranes 2020, 10, 82
2. Kujawa, J.; Rynkowska, E.; Fatyeyeva, K.; Knozowska, K.; Wolan, A.; Dzieszkowski, K.; Li, G.; Kujawski, W. Preparation and Characterization of Cellulose Acetate Propionate Films Functionalized with Reactive Ionic Liquids. Polymers 2019, 11, 1217.
3. Liu F, Wang S, Li J, Tian X, Wang X, Chen H, Wang Z. Polybenzimidazole/ionic-liquid-functional silica composite membranes with improved proton conductivity for high temperature proton exchange membrane fuel cells. J Membr Sci 2017; 541: 492-499.
4. Kraytsberg A, Ein-Eli Y. Review of advanced materials for proton exchange membrane fuel cells. Energy Fuels 2014; 28: 7303-7330.
5. Authayanun S, Im-orb K, Arpornwichanop A. A review of the development of high temperature proton exchange membrane fuel cells. Chin J Catal 2015; 36: 473-483.
6. Bai H, Wang H, Zhang J, Zhang J, Lu S, Xiang Y. High temperature polymer electrolyte membrane achieved by grafting poly (1-vinylimidazole) on polysulfone for fuel cells application. J Membr Sci 2019; 592: 117395


**1.5. Required initial knowledge and skills of the PhD candidate**

- Basic knowledge in the field of fuel cells, membrane separation techniques, membrane formation (phase inversion techniques), and membrane modification modification
- Basic knowledge in the analytical techniques used for membrane characterization, e.g. SEM, AFM, TG, IR and Raman spectroscopy, and impedance spectroscopy.
- Candidate applies and knows the principles of teamwork both at national and international level – possesses a good command of English.

**1.6. Expected development of the PhD candidate's knowledge and skills**

- The analytical and critical thinking
- Candidate knows new techniques and instrumentations, is critical in expressing opinions, discusses, is open to the issues raised.
- Candidate is eager to work hard and contributes to the success of the project
- Candidate is interested in the interdisciplinary research (material chemistry, electrochemistry, membranes