Chapter 13
Recent Progresses in Membranes for Proton Exchange Membrane Fuel Cell (PEMFC) for Clean and Environmentally Friendly Applications

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ABSTRACT

Fuel cell has become an emerging renewable energy device with potential to meet energy demand by portable and transport applications with zero-emission, easy operation, and compact design. The chapter provides an insight into design and development of membranes for PEMFCs and recent progresses made in membranes so far. Although majority of research has focused on fluorinated and non-fluorinated membranes, these polymeric membranes have showed deteriorated properties at elevated temperature (>80oC) and lower relative humidity (30%). Considering the major issues with polymeric membranes, the authors have reviewed inorganic-organic nanocomposite membranes showing improved physical and electrochemical properties at elevated temperature and lower relative humidity. Recently, metal-organic framework (MOF), a novel and unique material, has attracted tremendous attention due to their enhanced proton conductivity, easy functionality, and stability. MOFs have also exhibited excellent compatibility with different polymeric materials that are also discussed in this chapter.

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INTRODUCTION

Energy is among one of the necessities of human being. Heavy energy consumption worldwide, rapid depletion of available fossil fuels and their high polluting nature led to extensive research in the area of alternative sources of energy for achieving a clean and sustainable environment. At present scenario, it is hard to meet the total world energy demand only by one of the environmentally clean energy generation technologies. However, it could be possible to meet certain fraction of energy demand through rapidly developing energy conversion/storage technologies. One such class is the energy consumption by stationary, mobile and portable electronic devices, whose typical power requirement range is 0.5 W to 1000 kW, which is 10-20% of total world energy consumption (Carter et al., 2013). Addressing their power demand through new and renewable sources can reduce demand on the large stationary power generation systems. In last few decades, fuel cell, which utilizes large range of hydrocarbon fuels, has emerged as a potential candidate to fulfill the energy demand of portable applications largely. Performance of fuel cells depends on the judicious design and selection of effective and robust materials like solid proton exchange membranes (PEMs), electro-catalysts and bipolar plates.

Ion-exchange membrane (IEM), separating the electrodes, is the one of the major components of a fuel cell device. IEM plays a crucial role in enhancing the efficiency of the device based on its ion-transport properties. Typical IEM comprises of organic polymers matrix with acid functionalities such as carboxylic, sulfonic and phosphonic groups that dissociate when solvated with water which leads to transport of protons via vehicular (molecular diffusion) or Grotthuss mechanism (structure diffusion) (Strathmann et al., 2004). An ideal IEM should exhibit high proton conductivity, low electronic conductivity, less fuel crossover, cost-effective and high stability.

In past few decades, role of membrane in low temperature fuel cell such as polymer electrolyte membrane fuel cell (PEMFC) is a matter of debate among scientists due to deteriorating performance of device in terms of lower power density and its limited range of operation. To date, Nafion, developed by DuPont, USA in 1960, globally used as a PEM due to its homogeneous structure, high proton conductivity and remarkable stability. Unfortunately, Nafion is highly expensive ($ 200/m^2) and exhibits poor performance at lower humidity (30%) and high temperature (>80^{o}C) (Robert et al., 2011). Moreover, Nafion is very prone to fuel crossover (10^{-7} cm^2/s) and demonstrated dimensional instability. To address these issues, lost of efforts are being made to design and develop several polymeric membranes to overcome the complexities associated with Nafion.

In this direction, much emphasis has been also made to focus on inorganic-organic composite ion-exchange membranes synthesized by blending inorganic ion-exchangers like heteropoly acids (HPAs), zirconium phosphates (ZrP), inorganic metal oxides, carbon nanotubes (CNTs), graphene oxides (GO) into polymer matrix (PVA, PVDF, PEEK, PS) to enhance the properties of composite membrane (Nagarale et al., 2010). Recently, metal-organic frameworks (MOFs), a unique class of inorganic-organic co-ordination polymer, have also attracted tremendous attention due to their enhanced proton conductivity, easy functionality, and excellent structural stability (Yeo et al., 2014). These MOFs have also exhibited excellent compatibility with different polymers that make them a potential candidate as fuel cell membrane material. Herein, our aim is to brief recent progresses made in room temperature fuel cell membranes suitable for portable applications and address the current challenges.