Chemical Engineering Journal 309 (2017) 489–502

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Review

Recent progress of carbonaceous materials in fuel cell applications: An overview

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HIGHLIGHTS

- Carbonaceous are commonly used particularly in maintaining the performance of fuel cell.
- This study presents an overview of modifications of carbonaceous materials for application in Fuel Cell.
- It also summarizes the challenges faced in current fuel cell applications.
- And the use of carbonaceous materials to address these challenges.

ARTICLE INFO

Article history:
Received 11 August 2016
Received in revised form 11 October 2016
Accepted 13 October 2016
Available online 14 October 2016

Keywords:
Carbonaceous
Support
Hybrid membrane
Composite material
Fuel cells

ABSTRACT

Carbonaceous materials are commonly used in fuel cell applications, in which they play an important role in maintaining high performance. Recently, carbonaceous materials have been investigated as catalyst supports, electrode catalyst supports, hybrid composite components for membranes, storage systems and other applications, such as activated carbon in microbial fuel cells. This study presents an overview of several modifications performed on those carbonaceous materials to improve their structural and electrochemical properties and, hence, augment fuel cell performance. This review will mainly focus on the proton exchange membrane fuel cells (PEMFC) and direct methanol fuel cells (DMFC). Finally, this paper summarizes the challenges faced in current fuel cell applications and the use of carbonaceous materials to address these challenges.

Contents

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http://dx.doi.org/10.1016/j.cej.2016.10.051
1385-8947/

Fig. 1. JAQ MyFC portable charger [5].

1. Introduction

Greener and more environmentally friendly technologies continue to grow in popularity, and fuel cell technology is one of the most active areas associated with green energy. Currently, fuel cells have mostly been implemented in the automotive field. For instance, the Toyota Mirai [1], which uses a hydrogen fuel cell as its main power source, was recently launched (in 2014). Honda and Hyundai will also launch new vehicles, the Honda Clarity Fuel Cell [2] and Tucson Fuel Cell [3], respectively, in 2016. Furthermore, Europe's second largest airline, EasyJet [4], plans to implement a hydrogen fuel cell system in its planes.

Fuel cell technology is not limited to on-road vehicles, as it is renewable and cleaner compared to fossil-fuel-generated power sources. Its applications encompass our daily activities. Recently, in Mobile World Congress 2016, the Jaq fuel cell charger [5], produced by MyFC, was used to demonstrate the charging of mobile phones using only salt and water. Fig. 1 shows the design of JAQ MyFC portable charger which has been commercialized currently. Generally, fuel cell technology promises a pollution-free environment. The implementation of fuel cell technology in common appliances can lead to better worldwide energy security.

Fuel cells have attracted great attention from scientists and researchers, and considerable effort has been made to incorporate fuel cell technology into commercial products. The main drawback in the process of commercializing fuel cells is their low performance, which is limited by the poor conversion of chemical energy to electrical energy. The result is a relatively high cost per amount of energy produced. To establish fuel cells in the market of common commercial products, the performance of fuel cells must be increased to a level comparable to current energy sources. In the past few years, carbonaceous materials have been widely used to improve the performance of fuel cells, and different forms of carbonaceous materials have been incorporated as a result of their advantageous properties, such as high surface area, high electrical conductivity and relatively good stability in acid and alkaline media.

This review focuses on recent progress involving the different roles of carbonaceous materials in fuel cell applications. This review paper based on the selected papers published in the period 2011–2016. Mainly, polymer fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs) with carbonaceous materials are the subject of this review paper. This paper also discusses current challenges and anticipated future incorporation of carbonaceous materials in fuel cell applications.

Table 1
Properties of different carbonaceous materials.

Carbonaceous Materials	Properties/Characteristics	References
Carbon nanotubes	Diameter: ~4 nm High crystalline status, high surface area, large number of mesopores, high current carrying ability Drawbacks: Inert surface, poor catalytic activity (ORR)	[33,34,93]
Mesoporous carbon	Pore diameter: not more than 6 nm High surface area, tailorable surface functionalities, large pore volume with tunable pore size Drawbacks: Limitation of templating materials and preparation method – lead to pore volume <1 $cm^3\ g^{-1}$	[9,44,98]
Carbon black	Particle size: 50–100 nm Surface area: 800 $m^2\ g^{-1}$ Abundant, low cost, high electrical conductivity Drawbacks: low stability to corrosion, high ohmic resistance	[11,13,16,21,33]
Carbon nanofibers	Diameter: Depends on catalyst size High electrical conductivity, high oxidation resistance, low permeability to fuel, low cost Drawbacks:	[37]
Carbon aerogel	Pore size: <100 nm Surface area: 400–800 $m^2\ g^{-1}$ High strength, flexible, mechanically robust, high surface area Drawbacks: Brittle, friable	[99]
Carbon nanocoils	Specific surface area: 451 $m^2\ g^{-1}$ High graphitic characteristics Drawbacks: Cannot withstand extreme operating conditions	[100]
Graphene	One-atom thick 2D sheet of hexagonal arrangement of carbon atoms High surface area (2675 $m^2\ g^{-1}$), high electrical conductivity ($10^3 \sim 10^4$ S m^{-1}) Drawbacks: Tends to form irreversible agglomerates, graphitization	[43,49,63]
Fullerene	High electron affinity, high volumetric functional group density, better radical scavenging property Drawbacks: Low electrical conductivity	[61]

2. Roles of carbonaceous materials in fuel cell application

Carbonaceous materials, such as carbon nanotubes (CNTs) [6–8], mesoporous carbon [2,9,10], carbon black [11–13], carbon cloth [14], graphene [15], carbon nanofibers (CNFs) [16–19], carbon xerogel/aerogel [20], carbon nanocoils (CNCs) [21–23], fullerene [24,25] and activated carbon (AC) [26], have played important roles in fuel cell applications. Table 1 displays the properties for each type of carbonaceous materials. These carbonaceous materials are widely used as catalyst and electrocatalyst supports. Some of them are used as composite materials for hybrid membranes, and some play vital roles in the membrane electrode assembly (MEA) of the fuel cells. The use of carbonaceous materials in energy and hydrogen storage has received significant attention from researchers. Recently, activated carbon with some modifications has also been incorporated in fuel cells, especially in microbial fuel cell applications.