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Review article

Catalysts in direct ethanol fuel cell (DEFC): An overview

M.A.F. Akhairi [a], S.K. Kamarudin [a,b,*]

[a] Fuel Cell Institute, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

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ABSTRACT

Ethanol is a new fuel source employed in fuel cells because of its advantages such as low toxicity and lower market cost. Recently, two types of ethanol fuel cells have been developed: the acid and alkaline type Direct Ethanol Fuel Cell (DEFC). For both types of fuel cells, platinum was found as an excellent catalyst for the electrochemical reaction. However, recent research shows that palladium is a potential substitute for the costly platinum as the primary catalyst. Several studies reported that palladium is superior over platinum especially in alkaline environment. Thus, this paper briefly majorly presents both palladium and platinum catalysts used in oxidation of ethanol and highlight the remaining problems in the field.

Contents

* *Corresponding author*. Fuel Cell Institute, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia. Tel.: +60 389216422; fax: +60 389216148.
E-mail addresses: ctie@eng.ukm.my, ctie@ukm.edu.my (S.K. Kamarudin).

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Introduction

Ethanol is a C-2 type alcohol that is widely used for multi reasons. In recent decades, research on ethanol has been discovered for uses in various sectors including as a transportation fuel. In the U.S., ethanol has been a popular transportation fuel that reduces gasoline consumption. The fuel use of alcohol reportedly increased from 1.7 billion gallons in 2001 to 13.2 billion gallons in 2013 [1]. This drastic increase is mainly influenced by the local government. In 2011, the U.S. Environmental Protection Agency (EPA) allowed the addition of up to 15% of ethanol in pure gasoline for vehicles produced after 2001. Alcohol will reduce the cost of fuel transportation and emit less greenhouse gas when compared to conventional gasoline. The major setback of using ethanol is that because it is a short-chain carbon compound, ethanol has only approximately two-thirds the energy density (24 MJ dm^{-3}) of pure gasoline (34.2 MJ dm^{-3}). However, this setback will be mitigated, notably in transportation, as the price of fossil fuel is expected to increase because of the insufficient sources. Because ethanol may be obtained from simple processes such as fermentation, the price of ethanol will be more stable than gasoline. Fig. 1 shows the worldwide annual production of ethanol by country.

To exploit ethanol as fuel cell energy sources, process development and investigations are ongoing. The energy produced from a direct ethanol fuel cell (DEFC) is theoretically higher than the pioneer Direct Methanol Fuel Cell (DMFC). The complete oxidation of ethanol produced 8.0 kW h^{-1} kg^{-1} compared to the complete oxidation of methanol only producing 6.1 kW h^{-1} kg^{-1} [2,3]. This indicates that for the identical amount of methanol, more energy may be harnessed from ethanol, thereby reducing fuel consumption. In addition, ethanol is preferred over methanol because of its low toxicity. Health experts found that ingested methanol may damage the central nervous system, possibly leading to blindness. In addition, ethanol is produced in large amounts in the agriculture sector, allowing for a continuous availability and lower cost of resources. Due to ethanol similarities to methanol, DEFC have been identified to have a synonym cell system as DMFC system. Thus it will ease the development to implement ethanol as the fuel in fuel cell development.

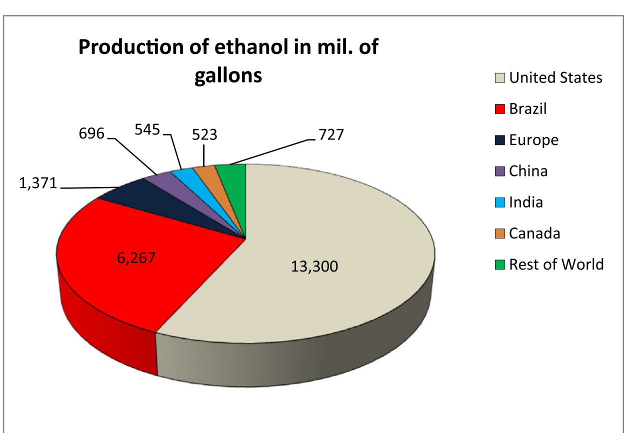

Fig. 1 – Production of ethanol in millions of gallons by worldwide countries in 2013 [1].

The primary objective of a DEFC is to convert ethanol into carbon dioxide via a complete oxidation reaction, thereby producing 12 electrons in a single reaction [4]. This surpasses the pioneering DMFC; DMFCs produce 6 electrons for each complete oxidation of methanol to carbon dioxide. The DEFC, however, displays a lower percentage of complete oxidation reaction compared to the DMFC. This lower rate is because of setbacks such as the chain in ethanol structure, type of catalyst, fuel structure, membrane used and physical factors such as the concentration and temperature. Thus a huge amount of studies are still required to increase the efficiency per mol of the fuel before ethanol may be used primarily as a new fuel source.

Acid type direct ethanol fuel cell

Ethanol may be oxidized in two type of environment; acidic and alkaline environment. Both environments implement different type of mechanisms but the same purpose in oxidizing the ethanol to produce electrons. Oxidation reaction of the fuel in acid type DEFC occurs at relatively low pH (less than pH value of 5). It uses the common membrane in acid that is Proton Exchange Membrane (PEM) which allows the movement of cations in the electrolyte [5–8]. The membrane is composed of structures of weakly bonded cations to complete the circuit throughout the phase. Common PEMs that are frequently used in studies are Nafion 115® and Nafion 117® type membranes which have been shown to be a good medium for PEM-DEFCs. In recent studies, PEM-DEFCs have shown a notable results, especially using platinum catalysts in acidic conditions [8,9]. Because the concentration of H^{+} is high in acidic media, the exchange of membrane cations is better compared to in alkaline media, thus PEM is suitable for a low pH environment phase. Fig. 2 displays the operation of a conventional acidic PEM fuel cell.

The fuel cell system is similar to DMFC since both uses acid buffer in the electrolyte. In the reaction, water is consumed at the anode and reformed at the cathode [8]. Over time, the concentration of ethanol in the anode compartment will decrease and requires replenishment of ethanol while the cathode in the other hand will increase in water