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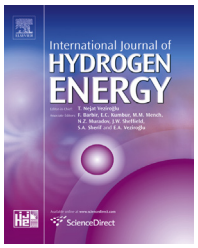

Review: Direct ethanol fuel cells

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ABSTRACT

Direct ethanol fuel cells have attracted much attention recently in the search for alternative energy resources. As an emerging technology, direct ethanol fuel cells have many challenges that need to be addressed. Many improvements have been made to increase the performance of direct ethanol fuel cells, and there are great expectations for their potential. However, many improvements need to be made in order to enhance the potential of direct ethanol fuel cells in the future. This paper addresses the challenges and the developments of direct ethanol fuel cells at present. It also presents the applications of DEFC.
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1. Introduction

Direct alcohol fuel cells (DAFCs) are a new source of energy that has recently attracted much attention. DAFCs area type of alkaline fuel cell (AFC). AFCs have shown that they can produce higher current densities than proton exchange membrane fuel cells (PEMFCs). PEMFCs are an emerging fuel cell technology and much attention has been given to them in recent years due to the flexiblity of using solid electrolytes and avoidance of electrolyte leakage. However, AFCs have other advantages, including their low cost and their low corrosiveness. In addition, AFCs are able to use relatively cheap and non-noble metal electrocatalysts, including nickel, silver and palladium, rather than platinum. This is due to the faster reaction kinetics of oxygen reduction in comparison to PEMFCs. Direct alcohol fuel cells (DAFCs) primarily use alcohol as fuel. The alcohols that are used as fuel in DAFCs are methanol, ethanol, ethylene glycol and 2-propanol [1]. Methanol, ethanol and 2-propanol have quite high energy densities of 6.09, 8.00 and 8.58 kW h kg^{-1}, respectively, and are comparable to hydro carbons and gasoline, which have energy densities of 10 and 11 kW h kg^{-1}, respectively [2]. Matsuoka et al. [3] found that DAFCs show excellent performance when conducted in alkaline media.

Conventionally, DAFCs used acid proton-exchange membrane (PEM) or Nafion-type membrane such as Nafion 117 and platinum type catalysts. This conventional DAFC let CO_2 generated from anode reaction of DAFC easy to remove in acidic electrolyte membrane but kinetic constraints of alcohol electro-oxidation relatively lower the performance of the system. Later on, some idea came out to shift the trend of DAFC to try alkaline media electrolyte or anion-exchange membrane (AEM). In alkaline media, DAFCs show better polarization characteristics in the oxidation of methanol on platinum than in acidic media. Furthermore, using alkali electrolytes allows for a greater possibility for application of non-noble and less expensive metal catalysts. By the way, alcohol permeation rate are reduced by the reversing of direction of ionic current due to hydroxide ion conduction against conventional proton conducting system [1,4,5].

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However, DAFCs face significant challenges due to the poor performance of electrocatalysts, in particular anode catalysts at lower temperatures, and anode surface poisoning by CO-like intermediates [2]. Instead of acid and alkaline media DEFC, there are other type of DEFC which combine alkaline-acid media in single cell where anode in alkaline media while cathode in acid media. The problem arise with acid and alkaline media is low theoretical voltage (1.14 V). The membrane type is used for alkaline-acid DEFC is cation exchange membrane/PEM type. Anion-exchange membrane (AEM) is neglected because of poor thermal stability and ionic conductivity lower than proton-exchange membrane (PEM). Table 1 shows several models of alkaline direct ethanol fuel cells (ADAFCs) with their maximum power density (MPD), Pt-containing ADAFCs with differing catalysts and (alkaline-anion exchange membrane) AAEMs, and operating temperatures. Table 2 provides similar information for Pt-free ADAFCs and AADAFCs (alkaline-acid direct ethanol fuel cells).

Previously, many researches had focused on the development of direct methanol fuel cells (DMFCs). Unfortunately, it has been found that DMFCs have several disadvantages. The issues with DMFCs are their sluggish reaction kinetics for methanol oxidation, methanol crossover through Nafion membranes to the oxygen electrode and anode poisoning by strongly adsorbed intermediates (mainly CO) [6]. Methanol crossover causes the fuel efficiency to decrease, as has been reported by many researchers. Methanol crossover also causes a mixed potential on the cathode, reducing cathode potential and also wasting fuel [7]. In addition, Matsuoka et al. [3] reported that DMFCs have slow electrode-kinetics, experience CO poisoning of Pt catalysts at lower temperatures and suffer from high material costs for the membrane, catalyst and separator. In fact, methanol is nonrenewable, has a high toxicity, is volatile and is a flammable substance. The use of methanol may result in major issues if applied to portable devices.

Ethanol is a good fuel choice for over coming the problems with methanol. In fact, ethanol is less toxic and has a higher energy density. It also can be produced from agricultural bioprocesses and is considered a renewable energy [8]. Additionally, ethanol has been proven by researchers to have a lower crossover rate and affects cathode performance less severely than methanol [9]. The development of electrocatalysts has mainly focused on PtRu and PtSn catalysts for DAFCs recently. PtRu/C catalysts are suitable for methanol, and PtSn/C in acidic environments is particularly suitable for ethanol. There are two types of direct ethanol fuel cells: proton exchange membrane DEFCs (PEM-DEFCs) and anion exchange membrane DEFCs (AEM-DEFCs). The primary challenge in PEM-DEFCs is the sluggish kinetics of the ethanol

Table 1 – Several model of alkaline direct ethanol fuel cell of some Pt-containing [1].

Fuel	Anode	Cathode	Electrolyte	Temperature (°C)	MPD (mW cm^{-2})
Methanol + KOH	Pt/C	Pt/C	AHA Tokuyama	50	5.5
EG + KOH					9.2
Methanol + NaOH	Pt/C	Pt/C	Morgane®-ADP, Solvay	60	6.8
Methanol + NaOH	Pt/Ti	Pt/C	Morgane®-ADP, 50Solvay	60	7.8
Methanol + KOH	Pt-Ru/C	Pt/C	AHA Tokuyama	50	6.2
EG + KOH (1 M)		Pt/C			9.5
EG + KOH (3 M)		Ag/C			8.1
Methanol + NaOH	Pt/C	Pt/C	Morgane®-ADP, Solvay	20	18
EG + NaOH					19
EG + NaOH	Pt/C	Pt/C	Morgane®-ADP, Solvay	20	19
	PtPb/C				22
	PtPbPd/C				28
	Pt/C	Pt/C	Morgane®-ADP, Solvay	20	19
		PtPb/C			23.5
EG + KOH	PtRu/C	Pt/C	A-006, Tokuyama	80	25
		Ag/C			20
		LaSrMnO/C			18
Methanol	PtRu	Pt black	QAETFE	50	1.5
				80	8.5
Methanol + KOH	PtRu black	MnO2/C	PVA/SSA	30	2.38
				60	4.13
Methanol + KOH	PtRu black	MnO2/C	PVA/TiO2	25	9.25
Ethanol + KOH					8.0
Methanol + KOH	PtRu black	MnO2/C	PVA/HAP	25	11.48
Ethanol + KOH	PtRu/C	Pt/C	PBI/KOH	75	49.20
				90	60.95
Methanol + KOH	PtRu/C	Pt/C	PBI/KOH	90	31
Methanol	PtRu	Pt black	AAEM-C	50	1.17
Ethanol					1.71
EG					1.57
Ethanol + KOH	PtRu	Pt black	AAEM, Tokuyama	20	58
Methanol + KOH	PtRu/C	Pt/C	AAEM, Tokuyama	20	6.8

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