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Review of implantable and external abiotically catalysed glucose fuel cells and the differences between their membranes and catalysts

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HIGHLIGHTS

- Ni, Pd, Pt and Bi are promising catalysts for the oxidation of glucose.
- Depletion and single layer designs are the best design for implantable fuel cells.
- Electrodes roughness factor has great importance at implantable glucose fuel cells.
- Glucose fuel cells with AEM and strong base present better performances than PEM.
- Catalysts poisoning by amino acids is the main drawback at implantable fuel cells.

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ABSTRACT

Abiotically catalysed glucose fuel cells (AGFC) can take two different forms, external and implantable. They can be used to power computers, mobile phones and other portable low-power devices, and to power implantable medical devices such as pacemakers or devices for electrical stimulation. At present, the maximum power density of implantable AGFC is about 6 $\mu W\ cm^{-2}$ whereas the maximum power density of external ones is around 35 $mW\ cm^{-2}$. Despite this value is still lower than that obtained from direct methanol and ethanol fuel cells, abundance of glucose make glucose fuel cells an interesting option to be developed. To achieve its commercial application, it becomes necessary to improve their performance and lifespan. In recent times, there have been remarkable advances in catalytic materials, electrodes structure and fuel cell layout, which have enabled to improve the power density and the poisoning resistance of both AGFC types. A critical and quantitative analysis on implantable and external AGFC and their materials has been conducted in this review. In general, Pt is not a good catalyst for glucose oxidation due to its high poisoning facility, and protective membranes that prevent the poisoning or other catalysts such as bimetallic catalysts (Pd–Bi, Pt–Bi) should be used in implantable applications. In external glucose fuel cells, Pd, Ni and other transition metals are good catalysts for glucose oxidation in alkaline medium, even better than Pt is. Moreover, new substrates (Ni foams or multi-walled carbon nanotubes) and catalysts (hierarchical, 3D or hollow) structures with high active surface should be further investigated.

Contents

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1. Introduction

In recent years, fuel cells have received a lot of attention from the scientific community because they are considered a very good alternative to traditional systems for producing electricity from fossil fuels. This is due to the large number of advantages offered by this kind of energy conversion system. They are simple, environmentally friendly, and highly efficient, more so than internal combustion engines. Moreover, fuel cells offer reliability and long life because they have no have moving parts, and their modularity makes it easy to increase production [1,2]. All these advantages have made fuel cells attractive for numerous purposes, ranging from mobile applications in cars, buses or motorbikes [3–5] to distributed, portable and backup power [6–9]. However, fuel cells could also be used in the medical field to power pacemakers, devices for electrical stimulation or deliver drugs and so on [10–13].

Hydrogen is the fuel most commonly used in fuel cells. Because the only by-product they produce is water, hydrogen fuel cells are a very environmentally friendly way to produce electricity. However, hydrogen has some drawbacks for certain applications. For example, it is not easy to store and distribute, and green hydrogen production is quite inefficient. For these reasons, other fuels have begun to be studied, such as methanol, ethanol and glucose. These fuels are more suitable for small portable applications, such as cellular phones, PCs and tablets [7,14,15].

This review focuses on glucose as novel fuel for fuel cells, and its elements and applications. Glucose is the most abundant monosaccharide in nature, opening up the possibility of use in conventional fuel cells. Though it is true that fuels such as methanol and ethanol have been widely studied for this purpose [16–21], glucose is still at the prior stage of bioalcohol extraction [22–24]. Researching the potential of glucose as a fuel is of great interest due to the possible savings in production costs, as glucose has a theoretical energy density (4430 Wh kg^{-1}) of the same order of magnitude as methanol (6100 Wh kg^{-1}) [25–28]. However, glucose is also an endogenous compound in body fluids, which opens up the possibility of utilisation with oxygen dissolved in body fluids in an implantable fuel cell. Lithium iodine batteries are currently the main power source for pacemakers and other implantable medical devices, such as implantable sensors and devices for electrical stimulation [10,29–31]. However, statistics show that their durability is lower than expected, and 60% of all pacemakers need to be replaced after 5–8 years due to battery depletion [32,33], instead of the expected 10 years [34]. Moreover, the new active medical implants, unlike pacemakers, are intended to treat diseases in patients of all ages, leading many research teams to study alternative power supply systems capable of operating for long periods of time without maintenance. Thus, patients would not have to undergo periodic surgeries to replace exhausted batteries. The options considered include the possibility of using thermal gradients in the human body to generate a current that can provide energy to low-power systems [33,35–38], or harnessing the mechanical energy produced by humans when they move to power sensors and other gadgets [33,39,40]. These approaches face the inherent problem of being dependent on the specific situation of the person carrying the device and the possibility of generating an electrical current. A third approach involves using fuel cells that can produce electric power from endogenous substances and oxygen by means of electrochemical reactions that take place in separate compartments.

1.1. Glucose fuel cells according to their location

Owing to duality of glucose, glucose fuel cells can be classified in two ways depending on the environment where they operate: external and implantable.

1.1.1. External glucose fuel cells

These are primarily intended for mass production of energy, similarly to methanol and ethanol fuel cells. They offer an alternative that does not require full prior purification of the reactants. This would make it possible to use agricultural waste and by-products for power generation, almost without prior treatment [25,27,41–43]. Certain plants, such as sugar cane or corn, are capable of generating large amounts of glucose by photosynthesis [24,26,41]. This type of fuel cell seems suitable for powering portable devices because glucose offers the advantage of being non-toxic, non-explosive and non-volatile, making it easier to handle than other fuels [44]. Moreover, it is also cheap, naturally abundant, environmentally friendly, and easy to produce [26,44]. In