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Direct power generation from waste coffee grounds in a biomass fuel cell

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HIGHLIGHTS

- Waste biomass is directly employed as a fuel with no any special treatment.
- Waste coffee ground is a fuel for SOFC-based carbon fuel cell technology.
- Carbonization and gasification take place under experimental temperature.
- Produced in-situ gaseous compounds highly enhance electrochemical reaction.

GRAPHICAL ABSTRACT

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ABSTRACT

We demonstrate the possibility of direct power generation from waste coffee grounds (WCG) via high-temperature carbon fuel cell technology. At 900 °C, the WCG-powered fuel cell exhibits a maximum power density that is twice than carbon black. Our results suggest that the heteroatoms and hydrogen contained in WCG are crucial in providing good cell performance due to its in-situ gasification, without any need for pre-reforming. As a first report on the use of coffee as a carbon-neutral fuel, this study shows the potential of waste biomass (e.g. WCG) in sustainable electricity generation in fuel cells.

1. Introduction

The worldwide clamor towards less dependence on fossil fuels, due to the emission of greenhouse gases and energy security issues, has led to the strong interest in using biomass energy [1]. As an alternative, renewable energy source, biomass absorbs the same amount of carbon dioxide (CO_2) during plant growth, contributing less to global warming. The only remaining issue, however, is how to produce energy from biomass without competing with food supply over the use of arable lands [1]. As such, utilization of waste biomass byproducts, especially from the food and beverage industry, is key to solving this problem.

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Waste coffee grounds (WCG) are an abundant resource for biomass-to-energy conversion technologies. The worldwide coffee consumption has steadily increased over the past decades, reaching an annual consumption of 8.8 million metric tons and leading to enormous amounts of organic wastes [2]. There have been various attempts in using WCG but most of these methods generate by-products that should be discarded in landfills or eventually incinerated [3–8]. For example, Sena da Fonseca et al. [3] found that WCG can be added to clay ceramics to enhance the mechanical strength due to increased water absorption and porosity. Several research groups [4–8] investigated the adsorption properties of polyhydroxy polyphenol functional groups in WCG and WCG-derived char on heavy metals. In addition, some researchers [9,10] studied WCG reforming with pyrolysis in order to produce bio-oil, which can then be processed to synthesize high value chemicals. Recently, biodiesel was produced from WCG [11,12], with the oil content, saponifiable lipids, and lipid profile varying according to the regional location and brewing technique [12].

On the other hand, using WCG as fuel in a carbon fuel cell technology with a solid oxide electrolyte renders multiple advantages. This electrochemical technology offers higher efficiency because it is not subject to Carnot limitations [13]. It mainly produces CO$_2$, which could be captured and reused, and a small amount of ashes, from which metals and/or other materials could be retrieved [14,15]. Additionally, it does not require intermediate conversion steps or pretreatment, improving the overall process efficiency relative to conventional methods [16–19]. Biomass-based carbon fuel cells can be categorized by a fuel treatment method: i. fuel as a carbonized biomass [14,15,20–22], ii. fuel as a gasified biomass (similar technique to that of integrated gasification fuel cell, IGFC) [23–26], and iii. fuel as an untreated biomass [27]. While there have been previous studies using biomass-based carbon fuel cells as recapitulated above, this is the first report on the performance of WCG-powered fuel cells, without the need for pre-treatment or gasification.

In this study, we showed the direct electrochemical oxidation performance of WCG-powered anodes, in comparison with that of carbon black (CB). A detailed analysis on the chemical composition and nature of WCG and carbonized WCG was performed in order to explain its electrochemical behavior.

2. Experimental

2.1. Preparation of biomass fuel cells

Waste coffee grounds (WCG, Tanay Hills Coffee Beanery, Hazelnut Arabica, Philippines) were dried at room temperature for three days (<50% relative humidity). Carbon black powder (ENSACO 350G, Timcal) was used as reference fuel due to its high carbon purity. The commercially available anode-supported button type cell was fixed to a Pt (99.9%, 52 mesh, Alfa Aesar) current collector using Ag paste (Fujikura Kasei). The cell, which is composed of Ni-YSZ as anode, 8YSZ as electrolyte, and LSM as cathode, was air-sealed using sealants (Thermiculite 866, the USA; Aremco ceramabond 668) to prevent combustion of fuels during the electrochemical reaction.

2.2. Electrochemical characterization

The fuel cell experiments were performed using an optimally designed apparatus consisting of an alumina ceramic reactor, a furnace and an electrochemical workstation (NARA Cell-Tech). The power performance tests were carried out at different temperatures: 750 °C, 800 °C, 850 °C, and 900 °C. The reactor was heated up at a ramping rate of 5 °C min^{-1} up to the desired reaction temperature. When the temperature reaches up to 600 °C from room temperature, the anode chamber was purged out by flushing pure Ar gas (99.999%) at a rate of 30 mL min^{-1} to eliminate internal O$_2$, which could oxidize the fuel. Meanwhile, pure O$_2$ (99.99%) gas was continuously fed at a rate of 50 mL min^{-1} to the cathode side.

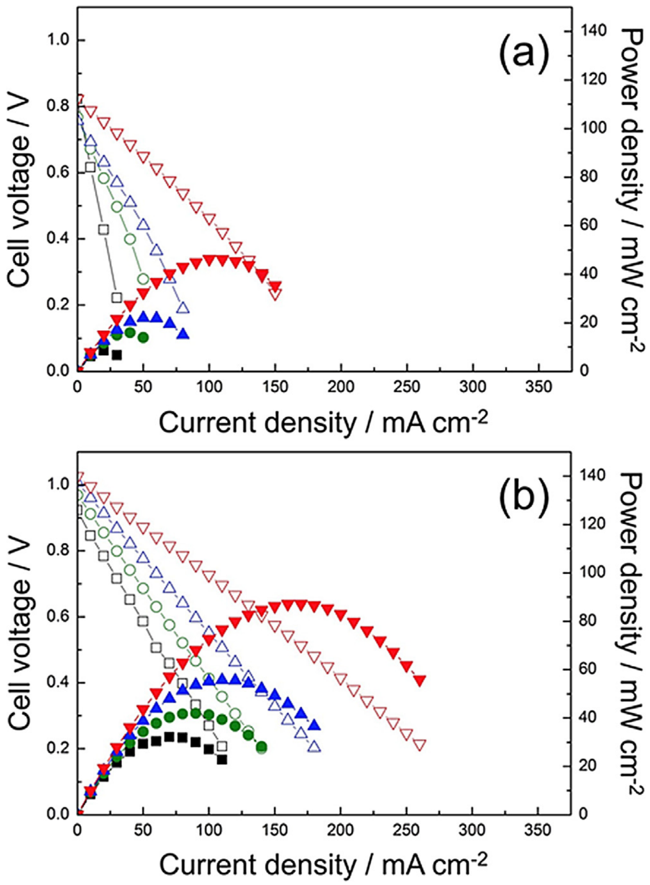

Fig. 1. Current-potential (*j-V*) and -power (*j-P*) curves of carbon fuel cells using (a) carbon black and (b) waste coffee grounds at different temperatures: ■ 750 °C, ● 800 °C, ▲ 850 °C, and ▼ 900 °C.

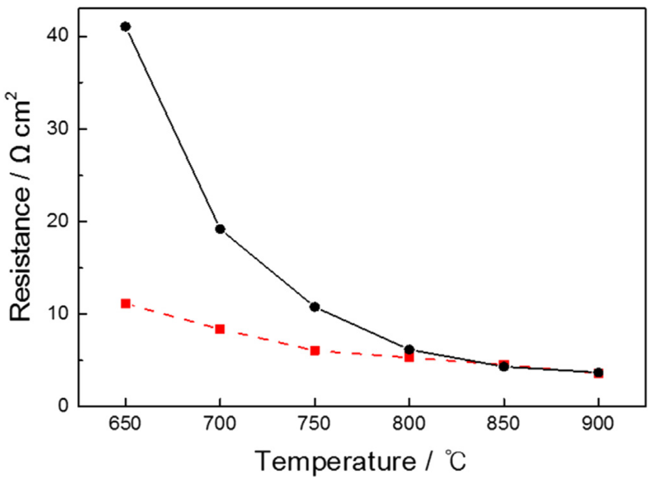

Fig. 2. The measured high frequency resistance of carbon black (black solid line with circles, ●) and waste coffee grounds (red dash line with squares, ■) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).