



Impact of gas products around the anode on the performance of a direct carbon fuel cell using a carbon/carbonate slurry



Hirotatsu Watanabe*, Daisuke Umehara, Katsunori Hanamura

Department of Mechanical Engineering, School of Engineering, Tokyo Institute of Technology, NE-6, 2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, Japan

HIGHLIGHTS

- An in situ observation around the anode is performed during the discharge of DCFC.
- Gas products prevents the carbon particles and ions from reaching the anode.
- The performance is influenced by the gas products around the anode.

ARTICLE INFO

Article history:

Received 1 June 2016

Received in revised form

26 August 2016

Accepted 29 August 2016

Available online 4 September 2016

Keywords:

DCFC

In situ observation

Gas products

Slurry

ABSTRACT

This paper investigates the impact of gas products around the anode on cell performance via an in situ observation. In a direct carbon fuel cell used this study, the anode is inserted into the carbon/carbonate slurry. The current-voltage (*I*-*V*) curves are measured before and after a long discharge in the constant current discharge mode. An in situ observation shows that the anode is almost completely covered by gas bubbles when the voltage becomes nearly 0 V in the constant current discharge at 40 mA/cm²; this indicates that gas products such as CO₂ prevent the carbon particles and ions from reaching the anode. Meanwhile, the long discharge at 20 mA/cm² is achieved for 30 min, even though the anode is covered by the CO₂ bubbles at 15 min. The *I*-*V* curves at 1 min after the termination of the long discharge at 20 mA/cm² are lower than those prior to the long discharge. The overpotential significantly increases at higher current densities, where mass transport becomes the limiting process. The cell performance is significantly influenced by the gas products around the anode.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Highly efficient energy conversion systems for converting solid fuels such as coal and biomass to electricity are required for clean energy production. Recently, the integrated gasification and fuel cell (IGFC) system, which incorporates a solid oxide fuel cell (SOFC), has attracted much attention [1,2]. After the pyrolysis of solid fuels, volatile matter and char are produced; the char is then gasified to produce H₂ in the IGFC system. However, a large exergy loss was observed in char gasification at 1100 °C [2]. Conversely, direct carbon fuel cells (DCFCs) directly convert the chemical energy in solid carbon into electricity without the need for a gasification process. The DCFC is an important device for minimizing the exergy

loss in energy conversion systems that use solid fuels. For example, a DCFC/SOFC combined system, in which volatile matter is used in the SOFC after reforming and the char directly used in the DCFC, has the potential to achieve very high efficiency. Although a wide range of designs and concepts has been tested, the overall efforts to develop DCFC technology have been relatively minor in comparison to the efforts devoted to other major fuel cell technologies [3]. Ordowich et al. forecasted coal and natural gas power generation technologies through 2050 [4]. In their model, IGFC becomes the dominant power generation technologies from 2030 onward, and DCFC technologies would likely become an important technology past 2050. Although there are many barriers to develop a practical DCFC such as lower power density, ash accumulation and continuous supply of carbon fuel [5,6], further investigation is necessary to overcome these issues.

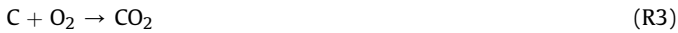
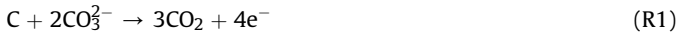
An important difference in DCFCs from other fuel cells is that the fuel is solid carbon particles, which possess a disadvantage in terms of reactivity and fluidity. A number of researchers have addressed

* Corresponding author. Department of Mechanical Engineering, School of Engineering, Tokyo Institute of Technology, NE-6, 2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, Japan.

E-mail address: watanabe.h.ak@m.titech.ac.jp (H. Watanabe).

this issue by developing DCFCs that use a carbon/electrolyte slurry, in which carbon particles are dispersed into the electrolyte to form a triple-phase boundary (carbon, electrolyte, and anode) [7–18]. Molten carbonates have often been used as an electrolyte because they offer many advantages such as high ionic conductivity [3].

The anode (R1), cathode (R2), and overall (R3) reactions in this system are expressed as follows:



The desired reaction is complete oxidation, which releases four electrons per carbon, as given by R1. The carbon wetting is an important factor in the formation of triple phase boundary [12,19]. Our previous study showed the carbon wetting has a significant impact on the continuous power generation capacity of the DCFC [12]. When the carbon particles are well-wetted by the molten carbonate, the anodic reaction process is described as follows: (1) carbon and carbonate ions are provided to the anode surface, (2) the anode reaction (R1) takes place at a triple-phase boundary, (3) CO_2 and electrons are produced. The transport of the carbon and the ion around the anode plays an important role in the power generation of the DCFC. In addition, it has been pointed out that CO_2 bubbles, which evolve from the electrochemical oxidation of solid carbon (R1), can potentially inhibit the cell operation and current stability [20]. Our previous study showed that bubbles were produced around the anode of the DCFC during discharge by using the single carbon pellet [13]. Although the impact of gas products around the anode on the cell performance should be addressed, little effort has been made to perform an in situ observation around the anode during discharge. Further investigations are still necessary to study the reaction and transport phenomena around the anode in order to improve the DCFC performance.

This study aims to study impact of gas products around the anode on the DCFC performance. The transport phenomena around the anode are studied through in situ observation and current-voltage (I-V) characteristics.

2. Experimental section

2.1. Carbon characterizations

Commercially available activated carbon (activated charcoal, Kantokagaku) was used in this study. Table 1 shows an elemental analysis (dry-base) and the ash content of the samples. The size distribution of the activated carbon particles, which was measured by laser diffraction (LMS-2000e, Seishin Enterprise Co. Ltd.), was shown in the supplemental material. By sieving commercially activated carbon, a size distribution ranging from 2 to 60 μm was obtained. The average size of the activated carbon particles was 16.7 μm . The crystalline parameters of the activated carbon were as follows: d_{002} (interplanar distance), L_c (the layer dimension perpendicular to the basal plane) and L_a (the layer dimension parallel to the basal plane) were 0.376 nm, 0.987 nm, and 3.22 nm, respectively.

Table 1
Elemental analysis of the activated chars [wt%, dry].

C	H	N	S	O (diff)	Ash
92.3	0.17	3.04	0.10	4.39	0.8

2.2. DCFC setup

Fig. 1 shows a schematic of a DCFC with a molten carbonate electrolyte, which was developed in our laboratory. Although further study of the electrode material is necessary for the high performance DCFC, in this study, the working electrode (WE), counter electrode (CE), and reference electrode (RE) were made from gold sheet which is immune to corrosion in the molten carbonate [21]. The area in contact with the carbon was 1.0 cm^2 . The RE and CE were in alumina tubes, and the WE was in a porous alumina tube (for separation of carbon particles, as described later). Each gold sheet was spot welded to the gold wire and extended to the other end of the tube to provide a connection to the potentiostat/galvanostat (HAL-3001, Hokuto Denko) for cell parameter measurements. The DCFC used in this study is similar to the one used in previous studies [11–13]. The part that differs is the quartz window attached to the plug above the anode for the in situ observation. A zoom camera (PowerShot SX50 HS, Canon) was used to record the phenomena around the anode as seen through the quartz windows.

A total of 240 g of dry ternary carbonate powder without carbon was placed in an alumina crucible with an inner diameter of 80 mm and a height of 70 mm. In addition, the mixed carbon/carbonate powder was contained in a porous alumina tube with an inner diameter of 15 mm. The average pore diameter of the porous tube

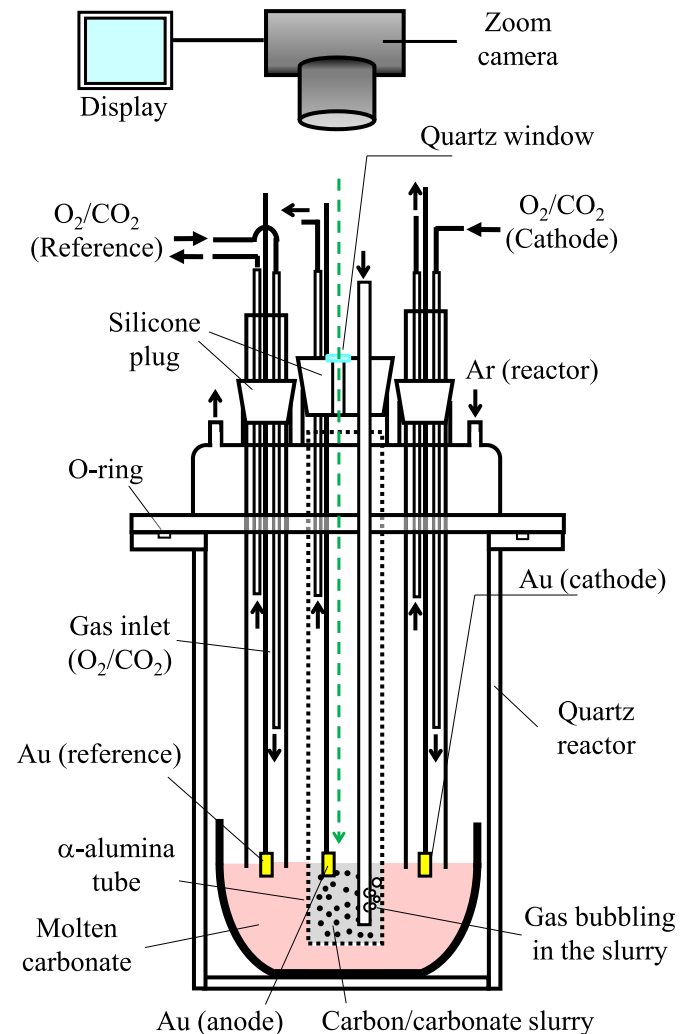


Fig. 1. Schematic diagram of DCFC with quartz window for the in situ observation.

Download English Version:

<https://daneshyari.com/en/article/7726795>

Download Persian Version:

<https://daneshyari.com/article/7726795>

[Daneshyari.com](https://daneshyari.com)