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Development of disk-type solid oxide electrolysis cell for CO_2 reduction in an active carbon recycling energy system

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Abstract

CO_2 recycling method characterized by the application of an Active Carbon Recycling Energy System (ACRES) to an iron-making process (iACRES) was studied. In this system, pure iron is produced from the reduction of iron oxide using regenerated CO by high temperature CO_2 electrolysis with the use of a disk-type solid oxide electrolysis cell (SOEC) and powered by a high temperature gas-cooled reactor (HTGR) generating electricity and thermal energy.

Thus, the focus of this research is to further improve the performance of disk-type SOEC by developing its structure and determining the most suitable electrode and electrolyte materials, and the appropriate fabrication method. In this present study, new cathode material such as Ni-SDC (SDC: samarium-doped ceria) was checked and tested for the SOEC. The electrochemical performance of the cells were evaluated at 800 ~ 900 ^{o}C by analyzing current-voltage characteristics, AC impedance spectra, and CO production data. Results showed CO production rates close to theoretical values corresponding to current density values observed. The performances of the SOEC samples were investigated for their potential use in iACRES, and the SOEC with Ni-SDC cathode showed the most enhanced electrochemical performance for iACRES.

The results showed that iACRES is available for utilization of the high temperature heat at about 850 ~ 950 ^{o}C provided by HTGR in this system. This would mean utilization of CO_2 emission-free thermal energy, and eventual expansion of use of nuclear energy beyond electrical power generation.

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Keywords: CO_2 reduction; carbon recycling; SOEC

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1. Introduction

With the world's increasing demand for energy comes with it the increasing concern for the environment, specifically the concentration of the released CO_2 to the atmosphere. To address this concern, there are many methods for CO_2 capture and recycling that are currently under economic evaluation. One such method being evaluated is the recently proposed Active Carbon Recycling Energy System (ACRES) [1]. In ACRES, CO is chosen to be the material recovered or regenerated because of its higher energy quality and density than hydrogen, as well as other hydrocarbons, and CO is a popular material for the iron-making and chemical industrial processes [2]. Regenerating CO from the CO_2 emitted as part of the blast furnace (BF) gas in an iron-making process would decrease its coking coal consumption and would also reduce CO_2 emissions in the iron-making process. This would be beneficial because the iron-making process is a big contributor to the global CO_2 emissions. According to the International Energy Agency as cited by the World Steel Association, approximately 6.7% of the total global CO_2 emissions comes from the iron and steel industry in 2010 [3].

The application of ACRES to an iron-making process is termed as iACRES (Smart Iron making process based on Active Carbon Recycling Energy System) [1]. In this system, pure iron is produced from the reduction of iron oxide using regenerated CO by a CO_2 reduction process with energy requirements provided by or harnessed from a high temperature gas-cooled reactor (HTGR) generating electricity and thermal energy. Figure 1 shows the concept of iACRES with the CO_2 reduction by high temperature (800 ~ 900 ^{o}C) direct CO_2 electrolysis with the use of a solid oxide electrolysis cell (SOEC) powered by HTGR.

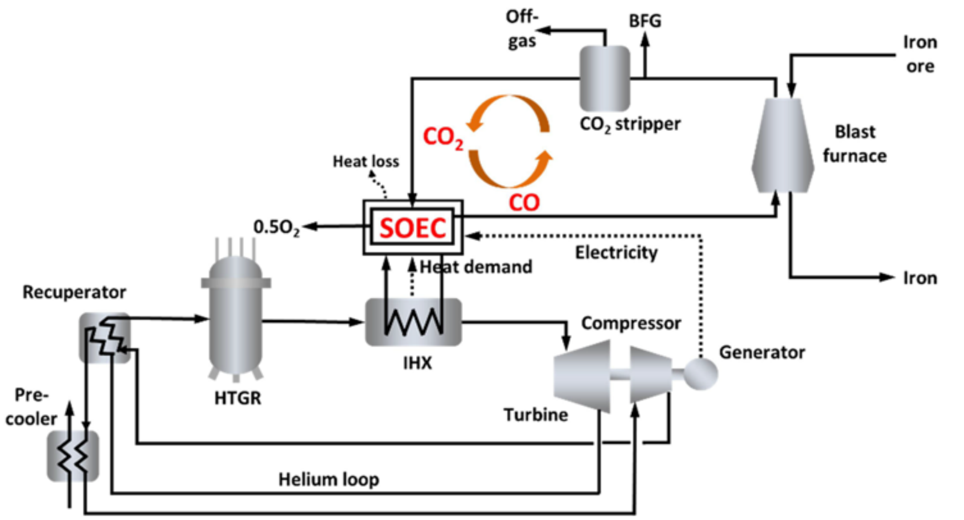

Figure 1. Schematic diagram of iACRES.

With iACRES utilizing HTGR as its primary energy source (supply of both electricity and heat required by the SOEC for CO regeneration via high-temperature CO_2 electrolysis) as shown by Figure 1, potential process heat application of HTGR is promoted. With the continuing development of more advanced and safe nuclear reactor systems, HTGR which is an inherently safe reactor is seen to be one of the promising candidates to cater to much stricter regulations in reactor operation. As such, it is considered as most suitable for utilization in iACRES as its energy source.

In iACRES, the regeneration of CO depends on the efficiency of the CO_2 reduction process via high temperature electrolysis using SOEC. Currently, the performance of high-temperature electrolysis of CO_2 via SOEC is limited by