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Ammonia-fed fuel cells: a comprehensive review

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ABSTRACT

The use of an ammonia-fed solid oxide fuel cell (SOFC) is the most efficient method of generating power. In terms of CO_2 emission, ammonia is a good indirect hydrogen storage material because it does not contain carbon and therefore will not release CO_2 when used as fuel in a fuel cell or gas turbine. Using ammonia like hydrogen directly in a fuel-cell system provides high power density. Compared with other fuel cells, the ammonia-fed SOFC has many advantages. The availability of NH_3 is one of the main reasons for the high output.

This paper presents a comparative study of the working principles, analyses, applications, advantages and disadvantages of various technologies available for ammonia fuel cells. The aim of the paper is to review and describe the suitability of ammonia as a fuel for the next generation of fuel cells, including direct ammonia-fed SOFCs, the development of different types of fuel cells using ammonia as a fuel, and the potential applications of ammonia-fed fuel cells.

Contents

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Organization of the review

The discussion about ammonia-fed fuel cells has organised in different sections in the review. It has been started with a brief introduction about the importance and types of fuel cells. It also describes the availability and production ammonia with its potential as a fuel in fuel cells. In Section 2, more about ammonia and fuel cells have been discussed, and subdivided into many sections. Ammonia resources and synthesis procedure has been discussed in Section 2.1. Section 2.2 describes about the progress of ammonia fuel cells with proton conducting electrolytes. A list of recent experimental results has been given in Table 2. Section 2.3 discussed about the applications of ammonia in agriculture (Section 2.3.1), industry (Section 2.3.2), as a hydrogen carrier (Section 2.3.3), power production and transportation (Section 2.3.4). Safety precaution and health impacts of ammonia have been described in Section 2.4. Section 2.5 describes about ammonia fuel cells in details with three subsections i.e. direct ammonia and alkaline membrane fuel cells (Section 2.5.1), direct hydrazine and ammonia borane fuel cells (Section 2.5.2) and direct ammonia solid oxide fuel cells (Section 2.5.3). Section 3 discussed about the thermodynamical analysis of the ammonia fuel cells with four subsections i.e. Principles of the direct ammonia-fed SOFC (Section 3.1 which is also subdivided to SOFC-O (3.1.1) and SOFC-H (3.1.2)), equilibrium potential of the ammonia-fed SOFC (Section 3.2), determination of the gas composition in the SOFC (Section 3.3) and efficiency of the ammonia-fed SOFC (Section 3.4). Similarly, electrochemical and mathematical analyses have been discussed in Section 4 with four subsections, i.e. working potentials (Section 4.1), ohmic overpotentials (Section 4.2), activation overpotentials (Section 4.3) and concentration overpotentials (Section 4.4). Sections 5 and 6 briefly describes about the electrode and electrolyte and temperature effects on the fuel cell performance, respectively. Comparison between oxide ion conducting and proton conducting electrolyte based ammonia fuel cells has been discussed in Section 7. Finally in Section 8, a cost estimation of fuels and fuel cells as well as future prospective of ammonia fuel cells has been discussed.

1. Introduction

The standard of living unevenly distributes around the word-that many regions are yet to develop infrastructure that will improve human's life. Against this background, energy is the single most important resource for human activity and the basis for national development. In 2012, the total electricity generation in the world was found to be about 22,668 TW h. Increase in population followed by rapid urbanization and industrialization represents the great global challenge in terms of energy resource management and development.

Existing standard technologies based on fossil-fuel combustion cannot satisfy the increasing energy demand that leads the significant views on sustainable alternatives. Several alternative sources of energy have been proposed including solar and wind energies, which have the potential to replace conventional route of energy generation. In fact, researches on the development of alternative energy resource, high efficiency technology, eco-sustainable energy conversion and storage concern have increased worldwide, especially since the Fukushima nuclear accident in March 2011 [1].

As the presence of challenges to overcome greenhouse gas emissions that arise from the use of non-renewable fossil fuels and to diversify renewable sources, fuel cells have been extensively investigated as a promising technology for clean and efficient power generation both for stationary and mobile applications owing to their high efficiency and low environmental impact.

Fuel cells provide an opportunity to develop thermodynamic systems that generate electricity on the basis of electrochemical reactions by consumption of reactants from external sources [2,3]. Moreover, fuel cells are recommended because of their high efficiency, low environmental footprint and attractive technology for the direct conversion of fuel to electricity. Fuel cells are categorized according to their operating temperature, efficiency, applications, costs and electrolyte materials. The classifications of fuel cell by electrolyte are considered to six major systems [4] as followed;

- Alkaline fuel cells.
- Phosphoric acid fuel cells.
- Solid oxide fuel cells (SOFCs).
- Molten carbonate fuel cells.
- Proton exchange membrane fuel cells.
- Direct methanol fuel cells.

Among these different types of fuel cells, SOFCs has big advantage on combination of environment-friendly power generation with fuel flexibility [5]. As SOFCs are practicability at high temperature between 1073 K and 1273 K, several alternative fuels such as hydrogen, biogas, bio-ethanol and bio-methanol can be directly used in an SOFC [6]. Although hydrogen is considered as an ideal fuel, there exist problems associated with its production, storage and transportation [7]. Emission of greenhouse gases resulting from the use of natural gas and methane rules out these as potential alternatives for energy production. In recent years, ammonia (NH_3) has emerged as a promising fuel for electricity generation in SOFCs because it is relatively cheap, carbon-free, easy to store and transport, less flammable than other fuels and relatively safe because any leakage is easily detectable from the odour [8]. Additionally, the infrastructure of ammonia technology