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A solid polymer water electrolysis system utilizing natural circulation

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ABSTRACT

Solid Polymer Water Electrolysis (SPWE) is a method to efficiently produce high-purity hydrogen gas using a polymer electrolyte membrane-based system. SPWE systems that utilize natural water circulation (resulting from a difference in buoyancy) are a promising technology, which need no additional circulation pump for water supply to the electrolysis cells, and generate no pressure difference between the hydrogen generation and oxygen generation chambers. However, despite not needing an accurate pressure control, gas bubbles formed and trapped within the cell stacks can inhibit heat convection, leading to hot-spot formation and consequent destructive degradation. Improving the reliability is therefore one of the most important technological issues in natural circulation SPWEs. In this study, hot-spot formation is studied both by numerical heat and flow analysis, and by experimental in-situ visualization. This leads to insights into the degradation mechanisms of SPWE stacks, and their possible solutions. An improved design for an SPWE cell stack is successfully fabricated, and reliable operation up to 5000 h is demonstrated.

Introduction

Polymer electrolyte water electrolysis

SPWE is an electrochemical hydrogen production method utilizing polymer electrolyte membranes [1–9]. This technology can potentially be combined with renewable power generation, nuclear power generation, and carbon dioxide capture and storage (CCS), resulting in a CO_2-free chemical energy storage system, utilizing excess (e.g. off-peak) electricity. The water electrolysis process in SPWEs is described by the following reactions to directly generate pure hydrogen and pure oxygen from water:

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Cathode: $2H^+ + 2e^- \rightarrow H_2$

Anode: $H_2O \rightarrow 2H^+ + 2e^- + 1/2O_2$

Total: $H_2O \rightarrow H_2 + 1/2O_2$

At the anode, water is catalytically decomposed into protons, electrons, and oxygen gas. The resulting protons are conducted through the polymer electrolyte to the cathode, where they combine with electrons to form hydrogen gas.

A schematic drawing of a water electrolysis cell is shown in Fig. 1. At the center is the polymer electrolyte membrane (for example, Nafion). Electrocatalysts consisting of Pt and Ir are printed on both sides of the polymer electrolyte membrane. A porous current collector layer is placed at the anode and cathode for the transport of electricity, water, hydrogen gas, and oxygen gas. This membrane electrode assembly forms the basis of the electrolysis cell. Both the cathode and anode are saturated with water to provide the feedstock for hydrogen and oxygen production, and for the required humidification of the polymer electrolyte membrane. Stacks of cells are constructed by stacking alternative layers of the MEAs and Ti-based metallic separator plates. Hydrogen and oxygen gases are produced at the electrode-electrolyte interfaces, and form small bubbles. Under normal operation, these diffuse and grow throughout the porous current collector, and exit the cell through the outlets along with the circulating water [10].

The typical voltage for water electrolysis is between 1.4 and 1.8 V, and the current density is generally around a few A/cm^2. Table 1 shows a comparison of some of the various different methods of producing hydrogen gas. Compared with these, SPWE has several major advantages: (i) it can produce high-purity hydrogen gas; (ii) it needs no additional supply of chemicals (such as aqueous electrolytes); and (iii) it can undergo maintenance-free operation [11,12].

Natural water circulation in SPWEs

In SPWEs, water is supplied to the cell stacks, and the generated gases (as well as heat) should be removed from the cell stacks. Generally, pure water is supplied to the stack, and acts as a coolant. The gas–liquid, two-phase mixture of water and hydrogen (or water and oxygen) flows through the outlet, to the water tanks. The gas is then separated from the mixture, and the water is recirculated through the stack.

At startup, the water is generally electrically heated at both outlet pipes and then water circulation is started using an electric pump. After the temperature reaches 80 °C the electrolysis is started, and the electric heaters are shut down. The hydrogen and oxygen that are produced raise the system pressure, and after this reaches a high enough value, hydrogen gas is provided as the product.

In this study, we attempt to realize efficient water electrolysis without the use of auxiliary pumping units [13], utilizing the principle of natural circulation. A schematic of such a system is shown in Fig. 2. The inlet flow is single phase (liquid water). However, the outlet flow is a two-phase mixture of hydrogen/oxygen gas and liquid water. This generates a difference in density, changing the buoyancy, and therefore causing a pumping effect. This leads to a phase-driven natural circulation of water. Water is supplied at the bottom of the stack to the cathode and the anode. The hot water tank acts as a separator to extract the gases, such that circulation is possible using a simple flow system. Any pressure difference between the hydrogen and oxygen chambers can be easily adjusted at the pressure equalizing hole described in Fig. 2, removing the need for a complex control unit to cancel the pressure difference. This could lead to improved electrolyte lifetime, better system safety, and enhanced reliability. A photograph of our experimental water electrolysis system is shown in Fig. 3, and the specifications are summarized in Table 2. The hot water tank is 710 mm in diameter by 2050 mm in height. The SPWE stack is positioned below the hot water tanks, and supplied by natural circulation without the need for an electric pump. The stack comprises 10 cells, with a total electrode area of 625 cm^2. This generates hydrogen gas at a rate of 5 Nm^3/h. The temperature of the hot water was maintained at 80 °C by internal exothermal processes, such as Joule heating.

Thermal management of electrolyzer cells is critical [14,15]. Therefore attempts have been made to explore the temperature distribution in stacks. In particular, the formation of hot spots can occur, and is one of the most important technological issues to be solved. The formation of such hot spots can destroy the MEA, due to the relatively low temperature tolerance of the polymer electrolyte membrane. Sufficient increase in temperature can lead to the formation of

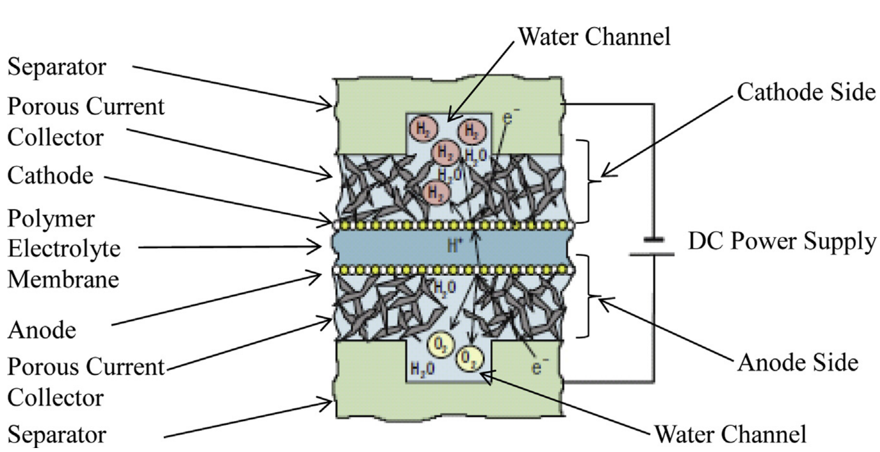

Fig. 1 – Structure of a typical SPWE cell.