Experiment Plan of High Temperature Steam and Carbon dioxide Co-electrolysis for Synthetic Gas Production

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1. Introduction

Currently, Solid oxide fuel cells (SOFC) come into the spotlight in the middle of the energy technologies of the future for highly effective conversion of fossil fuels into electricity without carbon dioxide emission. The SOFC is a reversible cell. By applying electrical power to the cell, which is solid oxide electrolysis cell (SOEC), it is possible to produce synthetic gas (syngas) from high temperature steam and carbon dioxide. The produced syngas (hydrogen and carbon monoxide) can be used for synthetic fuels. This SOEC technology can use high temperature from VHTRs for high efficiency. This paper describes KEPRI's experiment plan of high temperature steam and carbon co-electrolysis for syngas production using SOEC technology.

2. SOEC Process Description

The cell basically consists of three different layers. The middle layer is an ion-conducting electrolyte that is gastight. The left layer is the negative electrode and the right layer is the positive electrode.

High temperature (900°C) steam and carbon dioxide are fed to the cathode and electrons are forced to the cathode by an external voltage supply. This forces oxide ions (taken from H_2O and CO_2) to migrate through the electrolyte from the cathode to the anode.

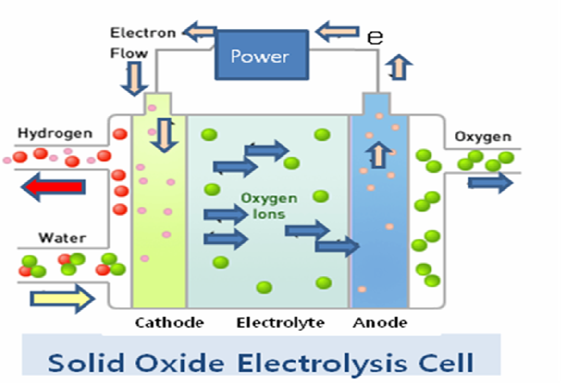

Figure 1. Process of Solid oxide electrolysis cell

3. Steam and Carbon Dioxide Co-Electrolysis

The overall reaction of the steam and carbon dioxide co-electrolysis is:

$$2H_2O \rightarrow 2H_2 + O_2. \quad (1)$$

$$2CO_2 \rightarrow 2CO + O_2 \quad (2)$$

The reaction at the cathode is:

$$2H_2O + 4e^- \rightarrow 2H_2 + 2O^{2-} \quad (3)$$

$$2CO_2 + 4e^- \rightarrow 2CO + 2O^{2-} \quad (4)$$

at the anode:

$$2O^{2-} \rightarrow O_2 + 4e^- \quad (5)$$

The minimum electric energy supply necessary for the electrolysis process is equal to the change in free energy (Gibbs free energy)

$$\Delta G = \Delta H - T\Delta S \quad (6)$$

where ΔH is the enthalpy change, T is the temperature in Kelvin and ΔS is the entropy change by the reaction. The total energy necessary for the electrolysis reaction is ΔH. $T\Delta S$ is the heat necessary for the reaction to take place. The relation between ΔG and the equilibrium potential (no current through the external circuit) for the cell is

$$\Delta G = nF\varepsilon \quad (7)$$

where n is the number of electrons involved in the reaction, F is faradays constant and ε is the equilibrium voltage, which sometimes is called the electromotive force. The value of ε is dependent on the actual partial pressures of the reactants and products as described by the Nernst equation.

Hydrogen is formed at the negative electrode (cathode) whenever a potential difference, V, larger than ε is applied to the electrodes of the cell, and steam supply is sustained to the negative electrode. The electric energy demand decrease as temperature increase. If the heat is produced at the negative electrode, the heat can be used to reduce the cell voltage.

4. Experimental System for Co-Electrolysis

CO_2 and H_2O are fed through the heat exchanger to the cell. Here it is split into H_2' CO and O^{2-} where O^{-2} migrates trough the gastight electrolyte and O_2 is formed at the positive electrode as long as steam is fed to the negative electrode. On the way out, H_2 and O_2 give off the heat to the incoming H_2O in the heat exchanger. The normal working temperature for SOEC is 950 °C.

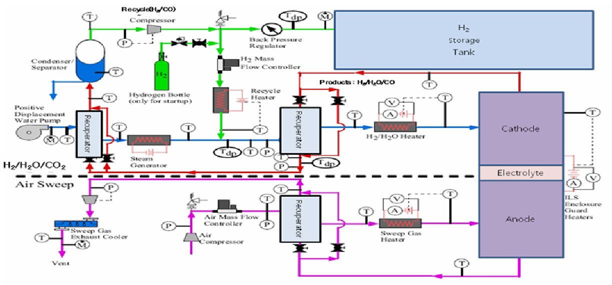

Figure 2. System Diagram for Co-Electrolysis

5. Experimental Apparatus Characteristics

5.1 Experimental apparatus

Schematic diagram of the experimental apparatus is shown in Figure 2. Steam concentration was detected by flow monitors, installed at the inlet and the outlet of the electrolysis vessel. Dry air from an air compressor is supplied outside the electrolysis vessel at a constant flow rate, which is also controlled with the mass-flow controller, in order not to decompose the anode compound of Sr-doped $LaMnO^3$ (LSM) under less oxygen partial pressure. The hydrogen concentration is measured by a gas flow meter. The electrolysis voltage is applied with a DC power supply. The electrolysis current is measured by a standard resistor of one ohm.

5.2 Gas Flow and Safety

All gases are placed within zone with ventilation facility in order to limit concentration below the explosion setpoint. A safety control system receives alarm signal from a number of sensors and controls magnet valves in order to reduce the explosion gases in a designated area if a concentration rise up above explosion limit values. The gas flow from normally closed valves is isolated. The normally open control valve opens and assures that the explosive gas is purged from the area.

5.3 Data Acquisition system

The computer system assures that the parameter values for all gas flow, voltage probes and voltage drop across resistors specified in the section is logged and stored on a hard disk every one minute. The computer is connected to the internet. The data communication system using a software interface on the computer enables us to set the high temperature gas and steam flow rate, change cell and evaporator temperature, set current load to the cell and to view the recorded data from a remote computer.

5.4 Flow Control

Nitrogen carrier gas from gas cylinders flows into a humidifier at a constant flow rate, which is controlled with a mass-flow controller and is mixed with steam at a specific partial pressure through the humidifier where carrier gas bubbled up through steam controlled at a constant temperature. Mixed gas is supplied inside the electrolysis tube

5.5 Temperature Control

The temperatures of the hydrogen and the steam/carbon dioxide gas are controlled to the designated setpoint by a sheath heater inserted in the electrolysis vessel. The hydrogen and carbon monoxide produced inside the cathode side, the unconverted steam and the carrier gas are cooled down to around 120 °C by a cooling pipe in order not to condense the unconverted steam. Air is supplied to the outside of the electrolysis vessel, which is heat up to 950 °C in the electric furnace. High-temperature air mixed with oxygen produced in the anode side is also cooled down in the recuperator at the outlet of the metal vessel. Five thermocouples are placed along the electrolysis vessel inner surface in order to measure the electrolysis cell temperature. Also, the surface temperature distribution of the electrolysis vessel is measured with several thermocouples. In the electrolysis vessel, the inner surface temperature distribution is almost the same as the electrolysis cell temperature distribution.

6. Conclusion

This conceptual design of co-electrolysis will be enable to produce syngas as hydrogen and carbon monoxide. In two year we will conduct the experiment of production of syngas using high temperature steam electrolysis. VHTR technology will increase the possibility for substantially increasing the efficiency of syngas production from carbon dioxide and steam without consumption of fossil fuels and emission of greenhouse gases. Thermal carbon dioxide and steam splitting for syngas production will be conducted through high temperature electrolysis using this conceptual design.

7. References

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