Current Status and Development Strategy for Nuclear Hydrogen Production With High Temperature Steam Electrolysis

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1. Introduction

Hydrogen is one of an important energy for future hydrogen economy and noted as the alternative energy substituting oil consumption. Domestic hydrogen demands are expected to increase from 1,600ton in 2015 year to 7.77million ton in 2040 year[1]. Current hydrogen production has primarily accomplished with steam methane reforming (SMR). But for large-scale hydrogen production, we should develop an advanced hydrogen production technologies that avoid consumption of fossil fuels and emissions of greenhouse gases.

Therefore, we are studying large-scale hydrogen production basis technology by using a nuclear power plant such as a very high temperature reactor and high temperature steam electrolysis.

In this paper, KEPRI's development status and future strategy for nuclear hydrogen production technology will be described and proposed.

2. Technical Development Status

2.1 Abroad development status of the demonstration pilot system for hydrogen production

Abroad countries such as US, Japan and China are actively implementing various projects for VHTR and hydrogen production with government supporting.

Through the Next Generation Nuclear Plant Project (NGNP), The DOE has established a demonstration reactor to be sited at Idaho National Laboratory (INL) by 2021[2]. Also, Idaho National Lab (INL) has been designated as the lead laboratory for high temperature electrolysis research and development, under the DOE Nuclear Hydrogen Initiative and achieved a technical advance in lab-scale integrated system[3].

Japan has already developed high temperature test reactor(HTTR) in 2004 and now developing hydrogen production technology for commercial use in 2020s. Japan's developing demonstration technologies are as follows : thermochemical water splitting IS process pilot at Japan Atomic Energy Agency [4] and by high temperature electrolysis unit-testing system at Toshiba Corporation [5].

2.2 Domestic development status of VHTR and hydrogen production technology

Technology Development for Nuclear Hydrogen Production in Domestic has been implementing at KAERI, KIER, KAIST and KEPRI.

KAERI carries out through the Nuclear Hydrogen Development and Demonstration (NHDD) and has established a plan to demonstrate massive production of hydrogen using a very high temperature reactor by the early 2020s [6,7]. Hydrogen production technology by thermochemical water splitting using the heat of solar energy or by SI process using the heat of VHTR is studying at KIER.

3. Hydrogen Production Technology

Currently, a promising massive hydrogen production technology is summarized as 3 methods as follows : Sulfur-Iodine Process (thermochemical cycle), Hybrid Sulfur Process (thermochemical), High Temperature Steam Electrolysis (HTSE).

Both sulfur-iodine and hybrid sulfur process require high temperature(>800℃) for reaction, extensive thermal management, and corrosion resistant materials. Also above three processes are performed an integrated lab-scale demonstration[3,8,9].

3.1 Sulfur Iodine Process

Sulfur-Iodine thermochemical cycle is originally proposed by General Atomics in 1970s and consists of three reactions : H_2SO_4 decomposition(1), hydrogen iodine (HI) decomposition(2) and Bunsen reaction(3)[3].

$$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2O_2 \quad (1)$$
>800℃, endothermic reaction, SNL

$$2HI \rightarrow I_2 + H_2 \quad (2)$$
>400℃, endothermic reaction, GA

$$2\,H_2O + SO_2 + I_2 \rightarrow H_2SO_4 + HI \quad (3)$$
<120℃, exothermic reaction, CEA

3.2 Hybrid-Sulfur Process

Hybrid-sulfur thermochemical cycle is developed Westinghouse Electric Corporation in the 1970s. It is a variant of the sulfur-iodine thermochemical cycle and involves a thermochemical and an electrochemical reaction[3].

$$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2O_2 \quad (4)$$
>800℃, thermochemical, SNL

$$2\,H_2O + SO_2 + e \rightarrow H_2SO_4 + H_2 \quad (5)$$
<120℃, electrochemical, SRNL

To carry out electrochemical reaction, Savannah River National Laboratory (SRNL) developed PEM Electrolyzer.

3.3 High Temperature Steam Electrolysis (HTSE)

This technology is water-splitting using nuclear energy and can achieve over 40% overall efficiencies of hydrogen production. In addition to, high temperature electrolysis can apply on existing solid oxide fuel cell (SOFC) technology.

The reaction of Solid oxide electrolysis cell (SOEC) is reverse reaction of SOFC and operates at the 800℃ over. Reactions are shown as follows.

Cathode : $H_2O(g) + 2e^- \rightarrow H_2 + O^{2-}$ (6)

Anode : $O^{2-} \rightarrow 1/2O_2 + 2e^-$ (7)

Total : $H_2O(g) + e \rightarrow H_2 + 1/2O_2$ (8)

3. Current Status and development strategy

For hydrogen production, SI process is more dominated for early demonstration in the short terms. But in the middle and long terms, High temperature steam electrolysis (HTSE) technology also promise to produce massive hydrogen. Therefore, we have selected HTSE process as the large-scale hydrogen production technology.

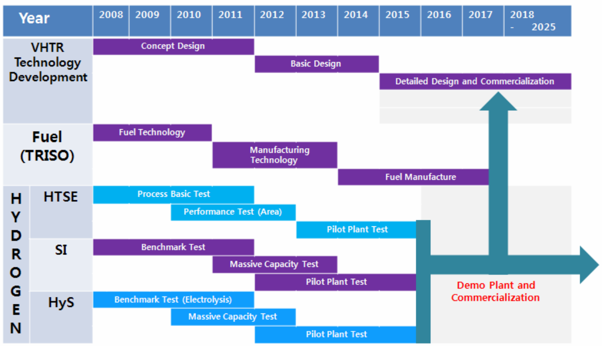

Fig. 1. Roadmap for Nuclear Hydrogen Development Project

Also, we have established technology development roadmap for very high temperature reactor and experiment plan of high temperature steam electrolysis (Fig.1). With the hydrogen production engineering system by SOEC (HyPESS), we will evaluate system efficiency and performance. And we will be collaboration with other organizations for development of hydrogen production system with VHTR.

5. Conclusions

According to increasing oil price, new alternative energy for substituting oil consumption and not using fossil fuel is required. Finally, hydrogen is the most promising energy for hydrogen economy and infrastructure. To develop massive hydrogen production technology, we are established development roadmap and are preparing the experiment plan of lab-scale integration system for hydrogen production by 2011.

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