Calculation of LUEC using HEEP Software for Nuclear Hydrogen Production Plant

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1. Introduction

Hydrogen demand is expected to sharply increase in near future as a development of technology using hydrogen as a new energy source. Contemporary hydrogen production is primarily based on fossil fuels, which is not considered as environments friendly and economically efficient.

To achieve the hydrogen economy, it is very important to produce a massive amount of hydrogen in a clean, safe and efficient way. Nuclear production of hydrogen would allow massive production of hydrogen at economic prices while avoiding environments pollution by reducing the release of carbon dioxide.

A Very High Temperature Reactor (VHTR) is considered as an efficient reactor to couple with the thermo-chemical Sulfur Iodine (SI) cycle to achieve the hydrogen economy[1].

HEEP(Hydrogen Economy Evaluation Program) is one of the software tools developed by IAEA to evaluate the economy of the nuclear hydrogen production system by estimating unit hydrogen production cost. In this paper, the LUHC (Levelized Unit Hydrogen Cost) is calculated by using HEEP for nuclear hydrogen production plant, which consists of 4 modules of 600 MWth VHTR coupled with SI process.

2. Methods

2.1 HEEP Program[2]

HEEP(Hydrogen Economy Evaluation Program) is a single-window software tool to estimate hydrogen cost in a comprehensive manner, which addresses economic aspects of all elements of hydrogen starting from its production to its distribution to the end-user. It can consider cost elements of plants and facilities involved in hydrogen production viz. source of energy required by the process generating hydrogen, production and storage of hydrogen, and its transportation to distribute to end user. The program can consider hydrogen generation plant attached to the nuclear power plant that supplies energy to hydrogen production process or isolated from the nuclear power plant. The isolated hydrogen generation plant works independently from the plant delivering energy source. Option is available to estimate the hydrogen cost with and without considering other auxiliary facilities for storage and transportation of the hydrogen.

2.2 Configuration of Nuclear Hydrogen Plant[3]

The nuclear hydrogen production system consists of four major sub-systems as explained below.

1) NHSS (Nuclear Heat Supply System)
NHSS is a VHTR reactor with a core outlet temperature higher than 950°C, which transfers energy in the form of either heat or electricity to the hydrogen production plant.

2) PCS (Power Conversion System)
PCS is a system that produces electricity from the high temperature heat from the reactor. PCS produces electricity using reactor high heat with gas turbine or steam turbine.

3) HTS(Heat Transport System)
The thermal heat generated from VHTR should be transported to the SI process to be used directly in hydrogen production. The pressurized helium gas is used as a working fluid to transfer heat from VHTR to SI process through the heat transport system.

4)HPS(Hydrogen Production System)
There are three potential nuclear hydrogen production processes, namely SI(Sulfur Iodine) process, HTE(High Temperature Electrolysis) process, and Hybrid Process.

3. Input Data to HEEP Software

3.1 Model Nuclear Hydrogen Production Plant

The four prismatic modular reactors coupled with SI cycle (VHTR, 4 x 600MWth) were chosen as a nuclear hydrogen production plant model for the LUHC calculation using HEEP software. The specifications of the nuclear hydrogen production plant are shown in Table 1.

Table 1. Specifications of Nuclear Hydrogen Production Plant

Design Parameters	Specification
Reactor Plant	VHTR
Hydrogen Plant	SI-Based Plant
Thermal Output	4 x 600 MWth
Operating LIfe	60 years
Plant Availability	90 %
Capacity Factor	90 %
Fuel Cycle	Open

The hydrogen production rate for four 600MWth prismatic modular reactors is calculated to be about 7.2 kg/s (205,000 tons/year), assuming a plant capacity factor of 0.9 and thermal efficiency of 48 %.

3.2 Input Data to HEEP Software[3]

The levelized unit hydrogen production cost(LUHC) was calculated using HEEP software. The costs for nuclear hydrogen production plant are summarized on an annual basis in Table 2 and this will be used as an input to the HEEP software to calculate the LUHC. The total capital cost includes all direct and indirect costs, nuclear fuel cost for the initial core plus interest during construction. The fuel cycle costs include nuclear fuel fabrication cost plus spent fuel waste handling and disposal cost.

Table 2. Summary of Costs for Nuclear Hydrogen Plant ($M/yr)

Account Description	Amount($M/yr)
Reactor Plant Capital Cost	115.7
Reactor Plant O&M Cost	73.4
Nuclear Fuel Cost	81.8
Decommissioning Cost	1.1
Total Annual Cost	272.0
SI Plant Capital Cost	85.1
SI Plant O&M Cost	34.8
Energy Cost	222.8
Total Annual Cost	342.7

4. Results

The levelized unit hydrogen production cost(LUHC) was calculated by the HEEP software and it was 2.15 $/kg for the model system as shown in Fig. 1. .

Fig. 1 HEEP Calculation Result for the model system

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