Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Preliminary economic analysis for co-generation system with steam methane reforming process and electrical generation system using 350 MWth HTGR

Taehoon Lee [a*], Juho Lee [a], Youngjoon Shin [a], Changkeun Jo [a]
[a] *Korea Atomic Energy Research Institute Daedeok-daero 989bungil 111, Yuseong-gu, Daejeon, Korea 34057*
[*] *Corresponding author: leeth@kaeri.re.kr*

1. Introduction

The HTGR has been considered a major heat source and the safest reactor among the generation IV type reactor. The heat source from the VHTR can be coupled with hydrogen production facilities such as SMR(Steam Methane Reforming), HTSE (High Temperature Steam Electrolysis), SI (Sulphur-Iodine) thermo-chemical process and Brayton/Rankine electricity production facilities. KAERI has developed various ways to configure the co-generation system with a hydrogen process and electricity production process.

In addition, a preliminary cost evaluation was performed for a NOAK (nth-of-a-kind) plant consisting of an HTGR coupled with the SMR hydrogen process and electricity production facilities. The thermal output of the reactor is 350MWth and the outlet temperature of the core is 750 ºC to 950 ºC

This paper presents preliminary economic analysis results for 350MWth based cogeneration system with SMR hydrogen production and electricity production in terms of the hydrogen production cost, electricity production cost and BC(Benefit to Cost) ratio and shows some sensitivity analysis results.

2. Evaluation Procedures

2.1 Evaluation Model

The co-generation model mainly consists of a nuclear power plant, hydrogen production system, and electricity production system. The HTGR supplies thermal heat to the hydrogen production system and electricity production system. The electricity generated from the electricity production system is also supplied to the hydrogen production process and surplus electricity can be provided outside as occasion demands.

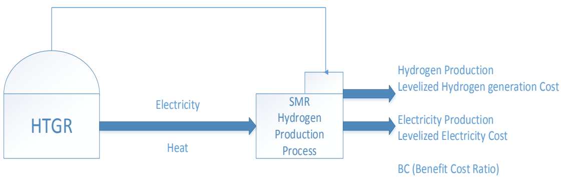

Fig. 1. Overall economic evaluation model

2.2 Hydrogen and Electricity production rate

For an evaluation of the economic cost value of the hydrogen production cost and electricity production cost, data on the amount of hydrogen electricity energy are essential. The hydrogen production rate for the 350MWth HTGR coupled with the SMR process and electricity is calculated based on preliminary top-tier system requirements for HTGR-based co-generation. The main strategy is to maximize the hydrogen production, and the electricity generated from the Brayton and/or Rankine cycle is self-consumed for the electricity energy demanded in the SMR process.

Table 1. Preliminary metrics for HTGR-based co-generation

HTGR thermal power	350 MW_{th}
HTGR outlet/inlet temperatures	
Very High Temp. Op. (VHTO)	950 ºC /490 ºC (ΔT=460 ºC)
Mid-High Temp. Op. (MHTO)	850 ºC /400 ºC (ΔT=450 ºC)
High Temp. Op. (HTO)	750 ºC /300 ºC (ΔT=450 ºC)
IHX outlet/inlet temperatures	
Very High Temp. Op. (VHTO)	900 ºC /470 ºC (ΔT=430 ºC)
Mid-High Temp. Op. (MHTO)	800 ºC /380 ºC (ΔT=420 ºC)
High Temp. Op. (HTO)	700 ºC /280 ºC (ΔT=420 ºC)
Cogeneration system	Hydrogen (main) and electricity
Hydrogen production process	SMR
Generator system	Brayton cycle and/or Rankine cycle

Based on Table 1, the primary and secondary helium flow rate can be derived as shown in Table 2.

Table 2. Primary and secondary helium flow rates

Operation mode	$\dot{M}_{primary\ He}$ (mol/s)	$\dot{M}_{secondary\ He}$ (mol/s)
VHTO	36,603.1	39,156.9
MHTO	37,416.5	40,089.2
HTO	37,416.5	40,089.2

KAERI developed a preliminary co-generation process flow diagram, and investigated a comparative evaluation for the SMR, HTSE and SI processes in terms of hydrogen production efficiency, thermal energy demand, and thermal utilization for each combination of HTGR outlet temperature through 750 ºC to 950 ºC and the hydrogen production process. [1]. With previous studies, KAERI has developed the material balance and heat balance for a co-generation system with the SMR process. As a result, we can obtain the basic hydrogen productivity and electricity productivity data for each outlet temperature, as shown Table 3.

Table 3. Co-generation rate of hydrogen and electricity with SMR

HTGR Outlet Temp.(ºC)	H_2 Productivity (Nm^3/h)	Total Electricity Production (MWe)	Surplus Electricity Production (MWe)
950	92,566	87.3	82.2
850	143,121	52.4	42.9
750	143,812	23.8	9.5

2.3 Basic input parameters and values

The levelized unit hydrogen production cost and the levelized unit electricity production cost was calculated for the co-generation system. We consider technical parameters such as the capacity of the plant, construction period, plant life, and cost and financial parameters such as the debt:equity ratio, interest rate, discount rate, O&M cost, and fuel cost. Most of them refer to the literature or KAERI's former studies and are modified from original literature value to meet the capacity size or Korean situations. The major basic parameters are described in Tables 4 - Table 6. [2] [3] [4]. The annual operation and maintenance cost are considered with a 3% interest rate. Among the basic parameters, the SMR capital investment, SMR O&M cost, and electricity facility Capital investment are changeable to the amount of the hydrogen production and electricity. The specific construction investment and annual O&M costs for the NPP, SMR and electricity facility will be presented at the conference because some numerical values are described in confidential report.

Table 4. Basic parameters for NPP

Parameters	**Value**
Capacity factor	90%
Construction period	5 years
Number of units	1 or 4
Capital investment * (Constant Price base)	Present at the conference
Annual O&M *	Present at the conference
Hydrogen generation method	SMR
Outlet temperature	750℃~950℃

Table 5. Basic parameters for Hydrogen/Electricity Production

Parameters	**Value**
Capacity factor	90%
Construction period	5 years
Number of units	1 or 4
SMR Capital investment (90% He flow rate)	Present at the conference
Electricity Facility Capital investment (90% He.flow rate) 1 Brayton, 1 Rankine	Present at the conference
Annual O&M for Hydrogen Facility (90% He flow rate) * Depends on total H2 production	Present at the conference
Hydrogen Price	5,500 KRW/Kg
Electricity Price (Industry)	107.11 KRW/KWh
Methane Cost	457.21 KRW/Kg

Table 6. Financial Parameters

Parameters	Value
Exchange rate	1,100KRW/$
Discount Rate	5.5%
Interest rate	2%
Equity to debt ratio	30%:70%
Cash flow rate % during construction period	OPR 1000 Reference
Operating life	60 years

2.4. Economic evaluation results

We changed the helium flow ratio for hydrogen production facilities and electricity production facilities from a ratio of 1:9 to 9:1 by steps. From the levelized unit cost calculation, we derived the price range for hydrogen production and electricity production, and the BC ratio. Table 7 shows the preliminary analysis results for co-generation with 4-modules HTGR and SMR. But credits caused by carbon-dioxide emission are not considered in this analysis. These credit can have decisive effect on production price and BC ratio. Thus, further studies for carbon-dioxide credits are needed to be done.

Table 7. Preliminary analysis results for co-generation with HTGR 4-modules (NOAK) and SMR ((): Median)

Temp(℃)	**Hydrogen Production Price (KRW/kg)**	**Electricity Production Price (KRW/kWh)**	**BC Ratio**
750	3294.7~ 8712.0 (3,839.6)	74.1 ~ 552.9 (171.1)	1.308 ~ 1.647 (1.579)
850	2636.6~ 8683.2 (3,244.0)	66.7 ~ 251.2 (117.8)	1.434 ~ 2.102 (1.900)
950	2811~ 12153.7 (3,747.1)	64.4 ~ 134.3 (91.3)	1.347 ~ 2.083 (1.815)

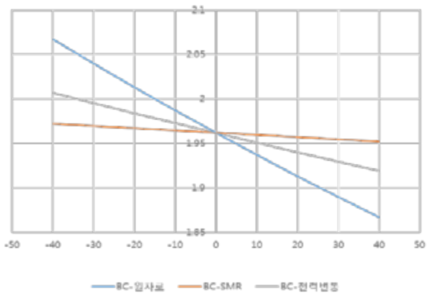

Fig. 2. Sensitivity to capital cost variation of HTGR, SMR, and electricity facility to BC ratio at 950℃ outlet temperature

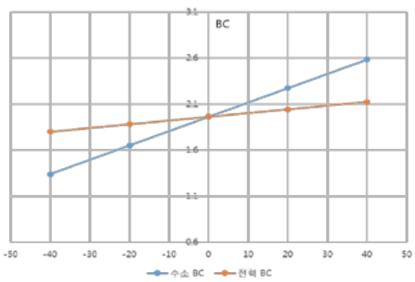

Fig. 3. Sensitivity to capital cost variation of hydrogen selling price, electricity selling price (for Industry) to BC ratio at 950℃ outlet temperature

3. Conclusions

This paper presented preliminary economic analysis results for a co-generation system using a 350MWth-based SMR hydrogen production with an electricity production. In addition, a parametric study was conducted for the major parameters that can affect the hydrogen production price, the electricity production price, and the BC ratio. The results show that the capacity factor, hydrogen selling price, construction cost and methane cost are more influential than the other parameters. However, it is necessary to adjust the parameter values to obtain a more precise economic evaluation. In addition, it is need to study for the carbon dioxide credits effects on the production prices and BC ratio.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2017M2A8A1014757).

REFERENCES

[1] T.H. Lee et al, Process analysis for a HTGR-based High Temperature Thermal Energy Utilization, KAERI/TR-6996/2017, KAERI, 2017

[2] W.J. Lee et al, The Study of Economic Analysis and Demonstration Research Plan for HTR Business, KAERI/TR-5891/2015

[3] Phillip Mills et al, High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics, INL/EXT-10-19037, INL, 2010

[4] A.M. Gandrik, Assessment for HTGR Capital and Operating Costs, INL, 2012

[5] Willard Lawrence Quon, A Compact and efficient SMR for Hydrogen Production, University of Houston, 2012