Effect of Recycled Sweep Gas on the Performance of HTSE Process

Ju Ho Lee*, Young-Joon Shin, Tae-Hoon Lee, Chang Keun Jo, Min-Hwan Kim
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Republic of Korea
*jhlee835@kaeri.re.kr

1. Introduction

High Temperature Solid Oxide Electrolysis(HTSE) is considered as promising technology for hydrogen production without carbon dioxide release for various heat sources. Mixture of steam and hydrogen are supplied to cathode of electrolyzer in which water dissociation reaction occurs and air or steam to anode of electrolyzer for the elimination of high temperature oxygen product gas. While air-sweep system is preferred against steam-sweep system in overall hydrogen production efficiency [1], the former requires additional electrical work required for the successive compression of inlet air stream to the operating pressure of electrolysis. This electrical work can be a factor lowering overall hydrogen production efficiency. In this study, for the reduction of electrical compression work for air-sweep system, the recycling of air sweep gas are considered and the effect of recycling on the performance of HTSE process coupled with 350MW High Temperature Gas Reactor (HTGR) are evaluated.

2. Process Flow-sheet development

Thermodynamic based 1-D electrolyzer model was proposed by INL researchers and employed for various case studies coupling HTSE with nuclear-based power production[1-3]. In this study, the same model was employed and all calculation for material and energy balance was conducted using EXCEL VBA code coupled with REFPROP 7.0.

2.1 HTSE Process coupled with 350Mw MTGR

Figure 1 shows the process flow diagram(PFD) for 350 MW HTGR slightly modified from the optimized INL flowsheet[3]. As listed in Table 1, Major differences lie in the reactor power from 600 MW to 350 MW, the operating pressure in helium loop from 7 Mpa to 4 Mpa and electrolysis from 5 Mpa to 1 Mpa. To describe realistic HTSE operation, temperature dependent ASR(Area Specific Resistance) with ASR_{1100K} = 1.25 [1] was employed for the present calculation

$$ASR = ASR_{1100K} - 0.463 + 0.00003973\exp(\frac{10300}{T/K}) \quad (1)$$

Other conditions such as the pressure drop in all process units are assumed to be the same with those in original flow sheet. Electrolyzer is assumed to operate at isothermal condition.

In calculation, the number of cell is adjusted until the full power cycle output matches the power requirement for electrolysis. The power efficiency of Brayton cycle was evaluated to 44.6% and overall hydrogen production efficiency was estimated to 40.57% with 5.01×10^6 electrolysis cells.

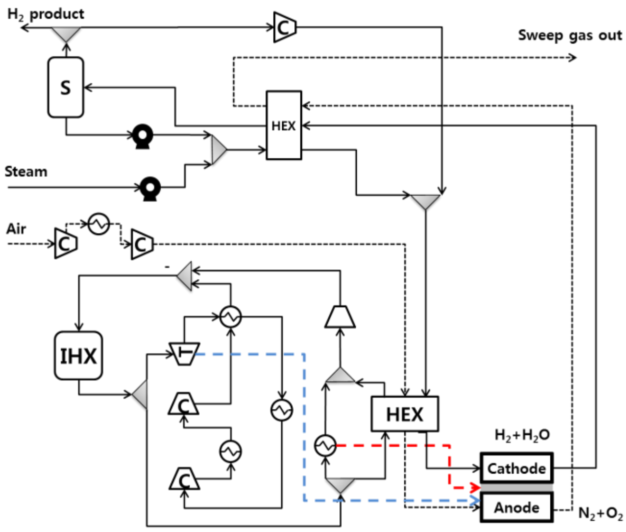

Fig. 1. PFD for HTSE coupled with indirect Brayton cycle

Table. 1: Specification for process simulation

Reactor thermal power	350 MW
Temp of IHX in/out stream	380 °C/800 °C
Desired current per cell	0.1
Electrolysis temperature	750 °C
ASR at Electrolysis temperature	1.723
Helium Loop operating pressure	4 Mpa
Electrolyzer operating pressure	1 Mpa

2.2 The effect of recycled air-sweep on performance

As revealed in Figure 1, air-sweep gas after heat exchanger is discharged to environment. In original INL flowsheet, this stream are delivered to turbin for additional power recovery, however, the temperature of final exit stream becomes significantly lowered to around -60 °C [3] indicating that such power recovery is actually infeasible. Although the temperature of air-sweep gas is not high enough for power recovery, the pressure of sweep gas implies that some of the energy inherent in sweep gas can be recovered. In this study, as shown in Fig.2, we consider that the partially recycled air-sweep gas is mixed with inlet air at the position post to the second compressor for inlet air stream. Figure 3 illustrates the overall hydrogen production efficiency evaluated at different recycled ratio. It indicates that as recycled ratio increases, the overall hydrogen production efficiency is linearly increased since as shown in Fig. 4, the amount of inlet air stream correspondingly becomes decreased reducing the compression power load for inlet air stream.

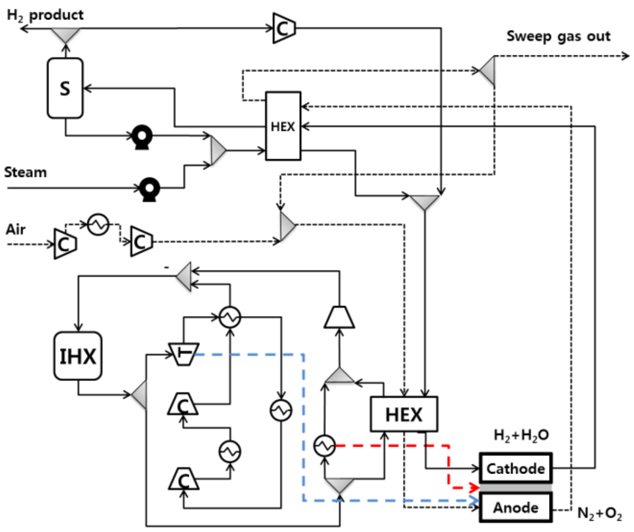

Fig. 2. The proposed PFD including the recycled Anode output stream

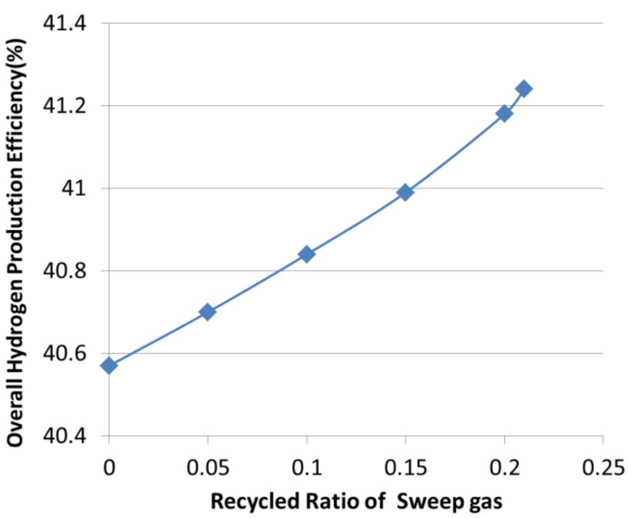

Fig. 3. Overall hydrogen product efficiency as a function of recycled ratio for isothermal boundary condition.

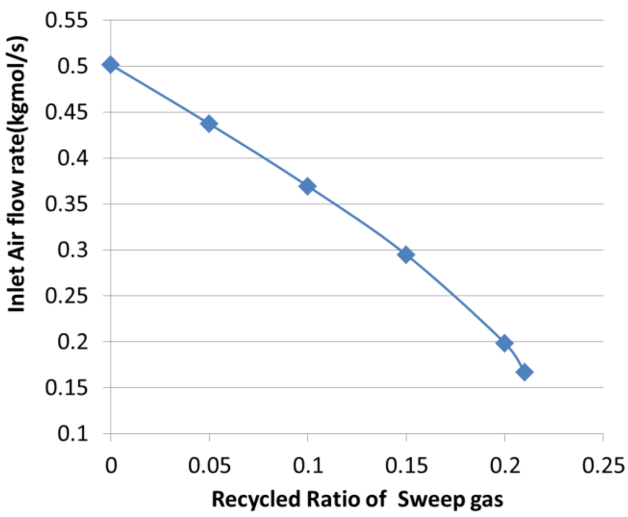

Fig. 4. Inlet Air flow rate as a function of recycled ratio for isothermal boundary condition.

3. Conclusions

For isothermal electrolysis operating condition, slightly higher overall hydrogen production efficiencies was achieved with the recycled gas sweep stream reducing the power requirement of injected air stream. The proposed strategy will be tested for adiabatic operation condition

Acknowledgement

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

REFERENCES

[1] C. M. Stoots, J. E. O'Brien, M. G. McKellar, G. L. Hawkes, Engineering Process Model For High-Temperature Electrolysis System Performance Evaluation, INL/CON-05-00725, AIChE 2005 Annual Meeting, 2005.
[2] J.H. KOH, D.J. Yoon and C.H. OH, Simple Electrolyzer Model Development for High Temperature Electrolysis System Analysis Using Solid-Oxide Electrolysis Cell, Journal of Nuclear Science and Technology, Vol.47, p.599, 2010.
[3] M. G. McKellar, J. E. O'Brien, E. A. Harvego, J. S, Herring, Optimized Flow Sheet for a Reference Commercial-Scale Nuclear-Driven High Temperature Electrolysis Hydrogen Production Plant, INL/EXT-07-13573, 2007.