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Preliminary estimations on the heat recovery method for hydrogen production by the high temperature steam electrolysis

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1. Introduction

As a part of the project 'development of hydrogen production technologies by high temperature electrolysis using very high temperature reactor', we have developed an electrolyzer model for high temperature steam electrolysis (HTSE) system and carried out some preliminary estimations on the effects of heat recovery on the HTSE hydrogen production system.

To produce massive hydrogen by using nuclear energy, the HTSE process is one of the promising technologies with sulfur-iodine and hybrid sulfur process. The HTSE produces hydrogen through electro-chemical reaction within the solid oxide electrolysis cell (SOEC), which is a reverse reaction of solid oxide fuel cell (SOFC). The HTSE system generally operates in the temperature range of 700~900 ℃.

Advantages of HTSE hydrogen production are (a) clean hydrogen production from water without carbon oxide emission, (b) synergy effect due to using the current SOFC technology and (c) higher thermal efficiency of system when it is coupled nuclear reactor.

Since the HTSE system operates over 700℃, the use of heat recovery is an important consideration for higher efficiency. In this paper, four different heat recovery configurations for the HTSE system have been investigated and estimated.

2. Process modeling and configuration of HTSE hydrogen production system (HTSE System)

2.1 Process modeling of HTSE system

A HTSE system model has been developed by using the HYSYS process simulation software, which is being maintained by Aspen technology. Fig 1 shows the process flow diagram of the HTSE system. The applied components in this diagram are material stream, energy stream, heater, cooler, separator, component splitter, mixer and a newly developed electrolyzer model.

The assumed initial conditions at the inlet and outside sides are summarized Table 1. Temperature and pressure of system in the both sides are assumed as 20 ℃ and 1 atm respectively. And the conditions for temperature and pressure within the electrolyzer model are assumed as 800℃ and 1atm.

The mixed gases of H_2O (status of stream), N_2, H_2 are heated up to the 800℃ and it is transferred to the electrolyzer model. High temperature electrolysis reaction in the inside the electrolyzer was modeled by conversion reactor component and the applied stoichiometric equation is $2H_2O \rightarrow 2H_2 + O_2$. After electrolysis, H_2/H_2O flows through the cathode and N_2/O_2 flows through the anode.

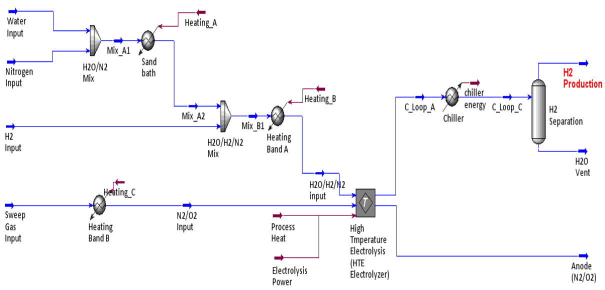

Fig. 1. Process flow diagram of the HTSE system without heat recovery loop (HYSYS)

Table 1: Assumed initial conditions

Side	Stream	flow rate (kg/s)	Sum (kg/s)
Inlet	Water (H_2O)	0.009	0.012
	Hydrogen (H_2)	0.001	
	Nitrogen (N_2)	0.001	
	Sweep gas (N_2,O_2)	0.001	
Outlet	H_2 Production (H_2)	0.0033	0.012
	H_2O Vent (H_2O)	0.0006	
	Anode(N_2,O_2)	0.0081	

Efficiency of the HTSE system based on the initial conditions (See Table 1) shows about 67.05 percents based on lower heating value of the produced hydrogen (LHV=242 kJ/mol-H_2).

2.2 Configurations and efficiency estimation for heat recovery of the HTSE system

If the high temperature (~800℃) at the electrolyzer outlet is used as a heating source at the electrolyzer inlet, system efficiency will be increased because of reduction of the external heat requirement.

Two different configurations for heat recovery loop were designed: (a) both water stream and sweep gas stream are heated by passing through the outlet of electrolyzer directly, (b) mixed streams of water and nitrogen are heated by passing through the outlet of electrolyzer after heating.

To estimate effects of the heat recovery loop on the HTSE system, additional heat exchanger components were added to the outlet of the electrolyzer (See Fig 2). Four different sub-configurations (cases) were considered (See Table 2). Results for the utilization of heat recovery loop system for the HTSE system shows that system efficiency increases over 10 percents than that of the HTSE system without heat recovery loop (Table 2). When heat recovery loop in the HTSE system is used, increase of efficiency is related to both heat exchange amounts in the heat recovery loop and heating temperature of flow streams before entering the electrolyzer model.

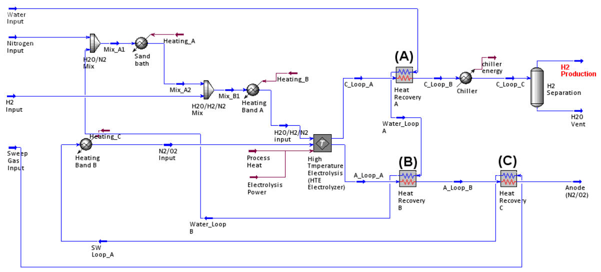

Fig. 2. Process flow diagram of the HTSE system with heat recovery loop (HYSYS)

Table 2: Configuration cases of heat recovery loop system

Case #	Location of heat recovery loop component		Efficiency* (%)
Case 1	Water (H_2O)	(A)	79.00
Case 2	Water (H_2O)	(A), (B)	80.93
Case 3	Water (H_2O)	(A), (B)	81.02
	Sweep (N_2,O_2)	(C)	
Case 4	Water (H_2O)	(A)	79.23
	Sweep (N_2,O_2)	(C)	

When both stream of water and stream of sweep gas are heated by heat recovery loop as like case 3 and case 4 at the Table 2, The efficiencies of two HTSE system show 81.02 % and 79.23 % , respectively.

If the mixed stream both water and nitrogen passes through the heat recovery loop after heating at the sand bath, the efficiencies of system are about 66.68 % (Fig.3) and it is lower than efficiencies of other cases listed in the Table 2. According to estimated results, we can determine the configuration for HTSE hydrogen production system with heat recovery loop as like case 3.

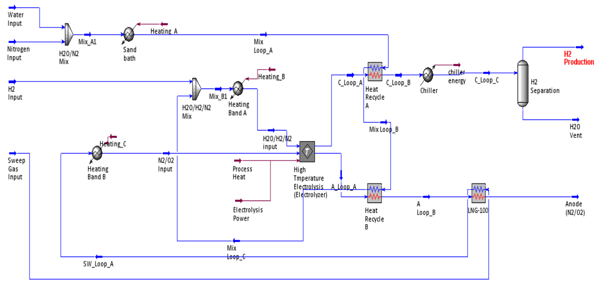

Fig. 3. Process flow diagram of the HTSE system with heat recovery loop (for mixed streams both water and nitrogen)

3. Conclusions

The basic configuration model has been developed for the HTSE system analysis and preliminary estimation for effects of heat recovery loop on the HTSE system has been implemented about the four different cases. When heat recovery loop is used in the HTSE system, thermal efficiency of system increases over 10 percents compared to without heat recovery. When we design the HTSE system, utilization of heat recovery loop at the outlet sides (cathode and anode) is highly recommended for both system efficiency increase and waste heat reduction within the system.

For optimization of the system efficiency and the hydrogen production, additional simulations and estimation for many configurations are required.

REFERENCES

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[2] Aspen Technology, Inc., Aspen HYSYS Ver. 7.0 : User's Guide, 2008.