Preliminary Study on Coupling High Temperature Gas Cooled Reactor with Hydrogen Production Systems

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1. Introduction

The hydrogen production system coupled with a High Temperature Gas Cooled Reactor (HTGR) is considered as one of the most promising application to allow new processes of massive hydrogen production with zero CO_2 emission. In the present study, a preliminary study is performed on various coupling options of two recent hydrogen production processes with HTGR: (a) Iodine-Sulfur (IS) system and (b) High Temperature Steam Electrolysis (HTSE) system. The total six design options are considered and the overall plant efficiencies are evaluated.

2. Design Options

2.1 General Description

The total six design options are considered in the present study as summarized in Table 1. The first option is a fully thermal system with IS system in which all produced thermal power is used for IS cycle and the required electric power is supplied externally. The other options (options II to IV) are the cogeneration systems with different configurations of IS system and power conversion unit. The required electric power is supplied by co-generated electricity. The two design options are considered for the coupling with HTSE system. In option V, all generated thermal and electric energy are used to supply thermal power and the Gibbs free energy required for the HTSE system operation. Option VI consists of multiple units in which thermal energy and electricity are supplied by different HGTR units. The efficiencies of Power Conversion Units are estimated using a similar type with the Brayton cycle of GT-MHR [1].

Table 1. Summary of design options for hydrogen production system.

Type	Option	Description
IS	I	Hydrogen-Only (Fully Thermal)
	II	Hydrogen + Electricity Cogeneration (Serial, Direct)
	III	Hydrogen + Electricity Cogeneration (Parallel, Direct)
	IV	Hydrogen + Electricity Cogeneration (Parallel, Indirect)
HTSE	V	Hydrogen-Only Hybrid (Thermal + Electricity) (Parallel, Direct)
	VI	Hydrogen-Only + Electricity-Only (Multiple Units)

2.2 Iodine-Sulfur System

An Iodine-Sulfur system of General Atomics [1] is adopted for coupling IS system with a 600MWth HTGR system in the present study. The peak operating temperature of GA IS system is 827°C and its operating efficiency is reported about 46.1% when the electricity efficiency is 50%. The reactor outlet temperature is estimated as 865°C assuming that the effectiveness of heat exchangers is 95%.

Figure 1 shows hydrogen production rate and overall plant efficiency with the fraction of thermal to total reactor power. When all thermal energy produced by a 600MWth HTGR is used for IS system, approximately 7.16 tons/hr of hydrogen can be produced with an overall plant efficiency of 38.1%. The estimated overall plant efficiency is somewhat lower than that expected.

The compressor work of helium coolant loop is a dominant factor in the evaluation of the overall plant efficiency. For example, the required compressor works are estimated as 42.2MWe and 22.5MWe for primary and secondary helium coolant loop in the fully thermal system (option I), respectively. In the cogeneration systems, the compressor work decreases as the proportion of generated thermal energy decreases (options II to IV). The cogeneration of hydrogen and electricity, therefore, could result in higher efficiencies than production of hydrogen only. However the design of cogeneration system entails a tradeoff between the overall plant efficiency and the proportion of hydrogen energy produced. The present calculation is performed when the peak operating temperature of IS process is 827°C and the overall plant efficiency will increase with the increase of the operating temperature.

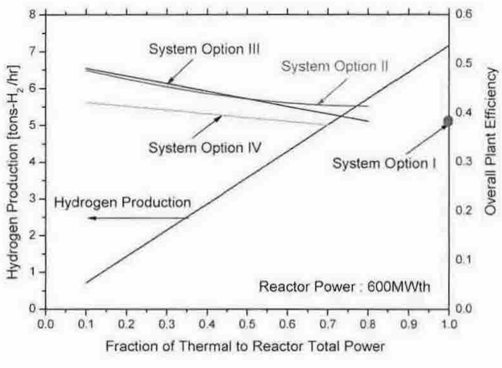

Fig.1 Hydrogen production rate and overall plant efficiency with the fraction of thermal to reactor total power.

2.3 High Temperature Steam Electrolysis System

An HTSE system is designed for coupling HTSE system with a 300MWth (PBMR) and a 600MWth (GT-MHR) HTGR systems in the present study. The HTSE cells are operated in an allothermal mode [3]. The hydrogen-steam mixture is heated up to a desired operating temperature through heat exchanger and super-heater, and then is fed to the inlet of HTSE cells. The heat from oxygen and steam-hydrogen mixture at the outlet of HTSE cells is regenerated to preheat the inlet feed of hydrogen-steam mixture.

A computer program is developed for the design of HTSE system coupled with HTGR as shown in Fig.2. The required Gibbs free energy with the HTSE operating temperature is calculated and the results show a good agreement with those of INEEL [4]. The Gibbs free energy tables are included in the program. The mixture states are obtained using water (ASME'92), hydrogen (INSPI), and oxygen (NIST) property tables. The efficiencies of the components such as AC/DC converter, pumps, heat exchanger, and electrolysis cell can be given as user inputs.

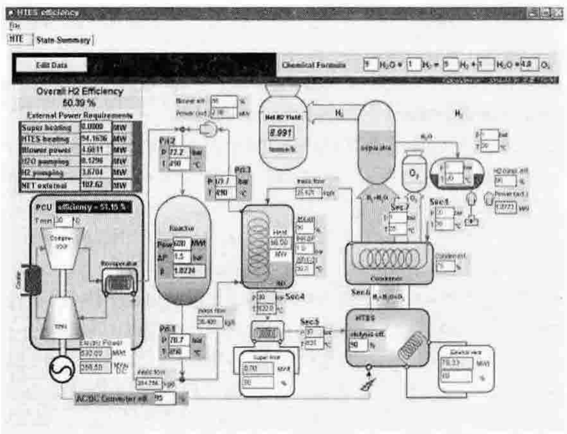

Fig. 2 Developed program for HTSE design.

Figure 3 shows the overall plant efficiency for HTSE system with respect to the reactor temperatures and the reactor thermal powers (option V). The efficiency increases with the increase of the reactor outlet temperature. The efficiency with GT-MHR is slightly higher than that of PBMR because the electricity efficiency of GT-MHR is slightly higher than that of PBMR. For the rector outlet temperature of 1000°C and 600MWth (GT-MHR) reactor the overall plant efficiency and hydrogen production rate are estimated as 54.35% and 8.28 tons/hr, respectively.

An HTSE system with multiple units is considered (option VI). One unit is hydrogen-only system with HTSE and its reactor power is used to supply the required thermal energy only. The required electric energy is supplied by other electricity-only units. Based on the result of option V, the ratio of the number of units for hydrogen-only and electricity-only systems is estimated approximately as 1:6.7.

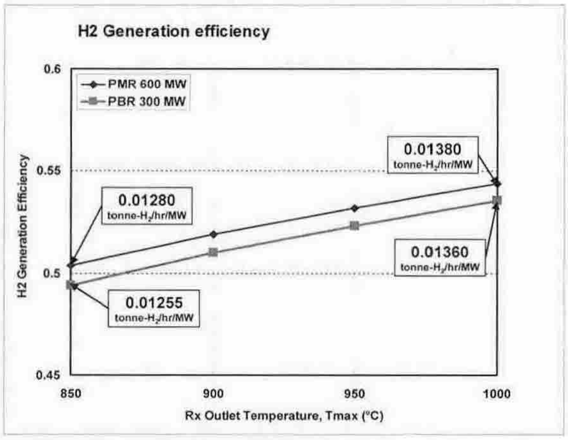

Fig.3 Overall plant efficiency with reactor outlet temperature.

3. Conclusions

A preliminary study is performed on various coupling options of two recent hydrogen production processes with HTGR: (a) Iodine-Sulfur (IS) system and (b) High Temperature Steam Electrolysis (HTSE) system. The total six design options are considered and the overall plant efficiencies are evaluated. It was found that both processes are viable technology for the massive production of hydrogen. For the IS process, cogeneration of electricity is recommended to increase overall plant efficiency. For the HTSE process, the improvement of system and component performance will increase the overall efficiency. We will further optimize the coupled system layout using more detailed information on the design and performance of reactor and hydrogen production systems.

REFERENCES

[1] Schleicher, R.W. et al., An Assessment of the Brayton Cycle for High Performance Power Plants, General Atomics Report GA-A23550, 2000.
[2] Brown et al., High Efficiency Generation of Hydrogen Fuels Using Nuclear Power, General Atomics Report GA-A24285, 2003.
[3] Rodriguez, G. and T. Pinteaux, Studies and Design of Several Scenarios for Large Production of Hydrogen by Coupling a High Temperature Reactor with Steam Electrolysis, EHEC-1, Grenoble, France, 2-5 Sept. 2003.
[4] Herring, J.S, et al., Hydrogen Production from Nuclear Energy via High-Temperature Electrolysis, Proceedings of ICAPP'04, Pittsburg, PA USA, June 13-17, 2004.