Simulation of a Secondary System for the Small-scale Test Loop

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1. Introduction

The High Temperature Gas Cooled Reactor (HTGR) with outlet coolant temperature up to 950 °C is considered as an efficient reactor for the thermo-chemical SI(Sulfur Iodine) cycle to be coupled for the hydrogen production[1]. The small scale high temperature test loop which is able to simulate the part of sulfuric acid decomposition process of SI cycle was installed in KAERI facility.

The test loop consists of primary and secondary system as shown in Fig. 1[2]. One of the key components in the test loop is the SO_3 decomposer, which receives heat from the nitrogen gas circulating in the primary system and transfers it to the sulfuric acid gas mixture circulating through the SO_3 decomposer in the secondary system. The purpose of the test loop is to confirm the integrity of the SO_3 decomposer under these high pressure and high temperature operating conditions.

In this paper, the secondary system of the test loop is simulated using aspen plus chemical process simulator to predict the behavior of the small scale test loop.

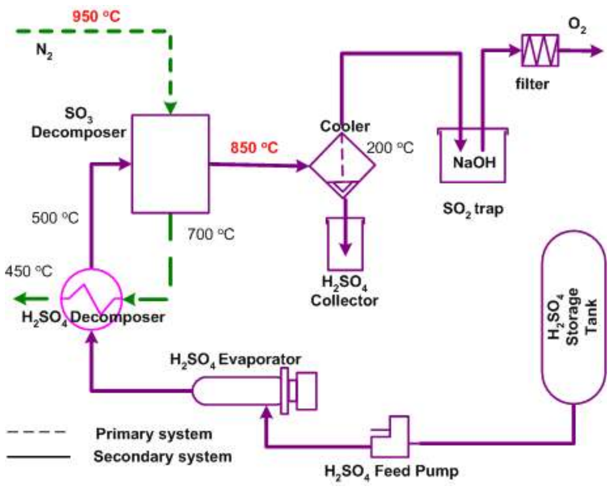

Fig. 1. Schematic diagram of the small scale test loop.

2. Test Loop Description

2.1 Primary System Description

The primary loop consists of circulator, SO_3 decomposer, pre-heater, main heater, hot gas duct and nitrogen supply system. The design conditions of SO_3 decomposer in the primary loop side are ;

- Working fluid Nitrogen
- Design Temperature 950 °C
- Design Pressure 4 MPa
- Design Flow 2.0 kg/min

2.2 Secondary System Description[2]

The secondary loop consists of H_2SO_4 feed pump, H_2SO_4 evaporator, H_2SO_4 decomposer, SO_3 decomposer, cooler, and SO_2 trap etc. The SO_3 and H_2O decomposed from H_2SO_4 is flowing in the secondary loop as a gas and its flow rate is controlled by a mass flow controller. The SO_3 is decomposed into SO_2 and O_2 in the SO_3 decomposer. The mixture of SO_2, O_2, and un-reacted SO_3 is cooled to form H_2SO_4 in the separator. SO_2 is removed by NaOH solution in the SO_2 trap. The design conditions of SO_3 decomposer in the secondary loop side are ;

- Working fluid H_2SO_4
- Design Temperature 900 °C
- Design Pressure 1.5 MPa
- Design Flow 1.0 kg/min

3. Simulation of a Test Loop

The simulation flow-sheet for the secondary system, as shown in Fig. 2 and Table 1, has been developed with unit operation models provided by the aspen plus chemical process simulator[3].

The streams are labeled in Fig. 2 and the temperature, pressure and mass flow rate are given in Table 1.

In the simulation, it was assumed that secondary system was operating at 0.7 MPa, 850 °C with 0.5 kg/min flowrate of sulfuric acid.

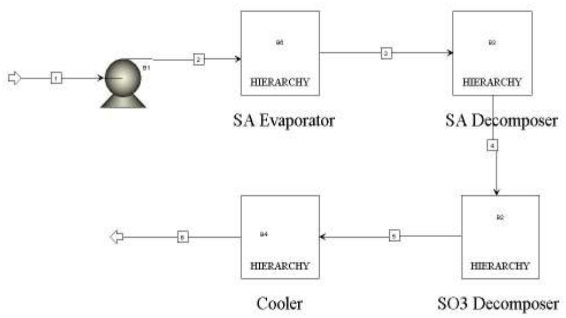

Fig. 2. The simulation flow-sheet for secondary system.

Table 1 : Material Balance for Secondary System

Substream	1	2	3	4	5	6
	LIQUID	LIQUID	VAPOR	VAPOR	VAPOR	MIXED
Mole Flow kmol/hr						
H2O	0.031055	0.031055	0.20575	0.329971	0.329971	0.215695
H2SO4	0.30017	0.30017	0.12547	1.25E-03	1.25E-03	0.11553
SO3	0	0	0.1747	0.298916	0.114275	0
SO2	0	0	0	0	0.18464	0.18464
N2	0	0	0	0	0	0
O2	0	0	0	0	0.09232	0.09232
Mole Frac						
H2O	0.093758	0.093758	0.40669	0.523646	0.456731	0.354654
H2SO4	0.906242	0.906242	0.248	1.99E-03	1.74E-03	0.189959
SO3	0	0	0.34531	0.474363	0.158175	0
SO2	0	0	0	0	0.255571	0.303592
N2	0	0	0	0	0	0
O2	0	0	0	0	0.127786	0.151796
Total Flow kmol/hr	0.331225	0.331225	0.50592	0.630141	0.722461	0.608185
Total Flow kg/hr	30	30	30	30	30	30
Temperature C	25	25.32105	429.49	750	850	119.85
Pressure atm	1	6.997286	6.99729	6.997286	6.997286	6.997286

3.1 Simulation of Sulfuric Acid Evaporator

Sulfuric acid is heated to the vaporization temperature before decomposition. It begins to vaporize during which some of the sulfuric acid decomposes into SO_3 and H_2O. The sulfuric acid evaporator is modeled as a combination of two flash tanks and one stoichiometric reactor in the simulation.

3.2 Simulation of Sulfuric Acid Decomposer

The sulfuric acid decomposer retrieves much of the heat remaining after sulfuric acid decomposition. The decomposition reaction of sulfuric acid proceeds further as the vaporized stream is heated through the sulfuric acid decomposer. Most of the sulfuric acid decomposes into SO_3 and H_2O before it exits the sulfuric acid decomposer.

The sulfuric acid decomposer is modeled as a combination of stoichiometric reactor and a heater in the simulation.

3.3 Simulation of Sulfur Trioxide Decomposer

Decomposition of SO_3 into SO_2 and O_2 is performed in sulfur trioxide decomposer. The outlet stream is cooled in the sulfuric acid decomposer, transferring heat to the sulfuric acid decomposer feed. The heat supplied from nitrogen gas is equal to the heat for sulfur trioxide decomposition plus heat needed to raise the gas mixture temperature[4].

The decomposer is modeled as a combination of stoichiometric reactor and a heater in the simulation. In case of sulfuric acid flow-rate of 0.5 kg/min, the total heat of reaction for sulfur trioxide decomposition is calculated to be 4.784 kW and the heat to raise the temperature of the gas mixture is to be 3.704 kW, assuming sulfur trioxide conversion ratio of 0.6177[5].

3.4 Simulation of Cooler

In the cooling process of the gas mixture, the remaining sulfur trioxide reacts with water vapor to form sulfuric acid which is collected in the sulfuric acid collector. The cooler is simulated as a combination of stoichiometric reactor and a heat exchanger in the simulation.

5. Summary

Material balance was established for the secondary system of a small scale high temperature test loop. The simulation result will be used as the information to design sulfuric acid evaporator, decomposer, and sulfur trioxide decomposer in SI cycle coupled with HTGR.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J. H. Chang et al., A study of a Nuclear Hydrogen Production Demonstration Platn, Nuclear Engineering and Technology, Vol. 39, No. 2, pp. 111-122
[2] S. D. Hong et. al. “Development of a Compact Nuclear Hydrogen Coupled Components (CNHCC) Test Loop,” American Nuclear Society 2007, Embedded Topical Meeting ST-NH2, Jun 25-30 Boston, USA, 2007
[3] Aspen Plus version 2006, Aspen Technology, 2007
[4] BROWN L.C. etc., High Efficiency Generation of Hydrogen Fuels using Nuclear Power, General Atomics Company, GA-A24285, 2003
[5] 김홍곤, “ IS 싸이클의 황산분해반응” , IS 공정 및 IS 열화학 황산분해공정기술개발과제 워크숍 발표자료, 2006