Design of a Sulfur-trioxide Decomposer Exchanging Heat between N_2 and Sulfuric-acid

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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 to be coupled with thermo-chemical SI(Sulfur Iodine) cycle for the hydrogen production[1].

The small scale test loop of 10kW capacity was installed at Korea Atomic Energy Research Institute (KAERI) facility to confirm the integrity of the sulfur-trioxide decomposer, one of the key components, under actual HTGR operating conditions

In this paper, the sulfur-trioxide decomposer was simulated with a chemical process simulator[2]. A standard shell-and-tube heat exchanger model in the simulator was chosen for the simulation.

2. Description of Sulfur-trioxide Decomposer

The sulfur-trioxide decomposer was assumed to be a standard shell-and-tube heat exchanger model.

The nitrogen gas is flowing into the shell side of the heat exchanger while the gaseous mixture of sulfur trioxide, water vapor, and un-reacted sulfuric acid is flowing in the tube side of the sulfur-trioxide decomposer.

While the gaseous mixture in the tube side receives 10 kW of heat from the nitrogen gas flowing in the shell side, the decomposition reaction of sulfur-trioxide into sulfur-dioxide and oxygen is catalytically taking place in the tube side of sulfur-trioxide decomposer.

The design conditions of the shell and tube side of the sulfur-trioxide decomposer are as follows;

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

Tube side
- Working fluid Sulfuric-acid
- Operating Temperature 850 °C
- Design Pressure 1.5 MPa.
- Design Flow 1.0 kg/min

In this case, 1 mole of sulfuric acid results in the gas mixture of 0.8 mole sulfur dioxide, 0.4mole oxygen , 1mole of vapor and 0.2mole sulfur trioxide.

3. Simulation of a Sulfur-trioxde Decomposer

The sulfur-trioxide decomposer is modeled as a combination of stoichiometric reactor and a heater in the simulation.

The information that was used in the simulation is that the decomposition of sulfur-trioxide starts at 675℃, and its decomposition ratio increases with temperature with about 0.8 at 825℃[3].

The sulfuric acid flowrate needed for 10kW heat transfer can be determined by taking heat balance around the sulfur-trioxide decomposer.

From the fact that the heat supplied from nitrogen gas is equal to the heat for sulfur trioxide decomposition plus heat needed to raise the gas mixture temperature.

$$Q_{N2} = Q_d + Q_s$$

, where Q_{N2} is the heat transferred from nitrogen gas, Q_d is the heat needed for sulfur-trioxide decomposition and Q_s is the heat needed to raise the temperature of product gas mixture.

Simulation model for sulfur-trioxide decomposer is shown in Fig. 1.

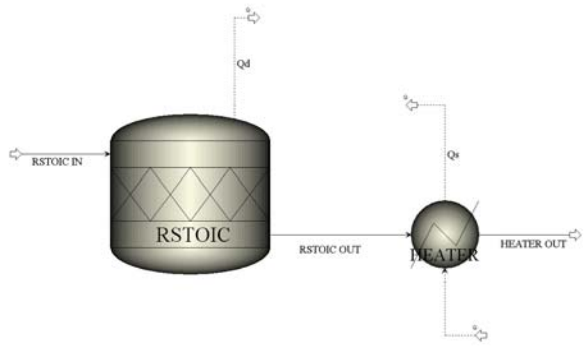

Fig.1. Simulation Model for Sulfur-trioxide Decomposer

The temperature, pressure and mass flow rate for each stream are given in Table 1.

Table 1. Material Balance for the Sulfur-trioxide Decomposer

	RSTOIC IN	RSTOIC OUT	HEATER OUT
Mole Flow, mol/sec			
H2O	**0.081**	**0.081**	**0.081**
H2SO4	**0**	**0**	**0**
SO3	**0.081**	**0.016**	**0.016**
SO2	**0**	**0.065**	**0.065**
N2	**0**	**0**	**0**
O2	**0**	**0.033**	**0.033**
Mole rac			
H2O	**0.5**	**0.416**	**0.417**
H2SO4	**0**	**0**	**0**
SO3	**0.5**	**0.083**	**0.083**
SO2	**0**	**0.333**	**0.333**
N2	**0**	**0**	**0**
O2	**0**	**0.167**	**0.167**
Total Flow, mol/sec	**0.162**	**0.195**	**0.195**
Temperature,℃	**500**	**500**	**900**
Pressure, bar	**7.09**	**7.09**	**7.09**

4. Sensitivity Analysis

Sensitivity analysis is performed for sulfur-trioxide decomposer. Moles of the mixture that exist inside the sulfur-trioxide decomposer are represented as a function of temperature in Fig 2. It is shown the moles of sulfur-trioxide decreases with operating temperature, while the moles of sulfur-dioxide and oxygen are increasing as the decomposition reaction proceeds.

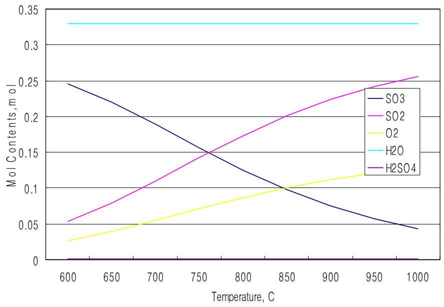

Fig. 2. Mole Contents Change during Decomposition Reaction

5. Summary

Material balance was established for the sulfur-trioxide decomposer with unit operation models with a chemical process simulator. It indicated that sulfuric-acid flowrate of 0.5 kg/min can receive 10kW heat transferred from nitrogen gas.

It also indicated about 6.3 kW of heat is used for the decomposition reaction and the other 3.7 kW of heat is used to raise the temperature of the product gas mixture from 500 ℃ to 900 ℃.

ACKNOWLEDGEMENTS

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