Determination of Sulfuric Acid Flowrate for PHE in a Small-scale Test Loop

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1. Introduction

The Very-High Temperature gas cooled Reactor (VHTR) with outlet coolant temperature up to 950 °C is considered as an efficient reactor for the hydrogen production in connection with a thermo-chemical SI(Sulfur Iodine) cycle.[1] The small-scale high temperature test loop was designed conceptually to simulate sulfuric acid decomposition process of SI cycle with VHTR operational conditions, 950 °C and 4 MPa. The test loop , as shown in Figure 1, can be divided into primary and secondary test loop.[2]

The purpose of the test loop is to test the integrity of the PHE under these operating conditions. As part of a construction of small-scale test loop, the primary loop with 10kW capacity was already installed at KAERI facility. The primary loop consists of circulator, pre-heater, main heater, hot gas duct, air cooler, process heat exchanger (PHE) and nitrogen supply system. One of the key components of the test loop is a process heat exchanger (PHE), which receives heat from the nitrogen gas circulating primary loop and transfers to sulfuric acid circulating secondary loop. The secondary side of PHE should have both high corrosion resistance against sulfuric acid and the strong thermal and mechanical resistances at high temperature and pressure (950°C, 4MPa).

In this paper, the flowrate of sulfuric acid circulating the secondary loop will be determined to match 10 kW capacity of primary loop.

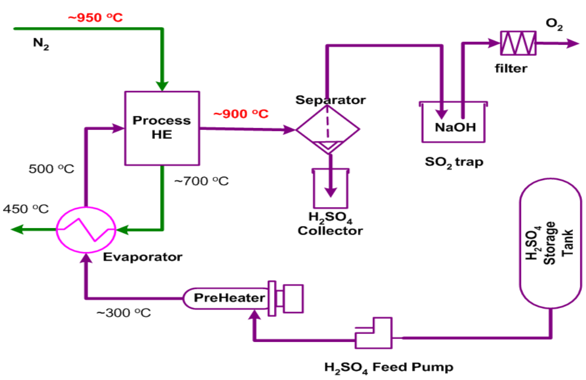

Figure 1. Schematic diagram of a small-scale test loop

2. Test loop description

2.1 Primary loop description

The primary loop consists of circulator, process heat exchanger(PHE), pre-heater, main heater, hot gas duct and nitrogen supply system. The design conditions of PHE in the primary loop side are ;

- Working Fluid	Nitrogen
- Operating Temperature	950 °C
- Operating Pressure	4.0 MPa.
- Design Flow	2.0 kg/min

2.2 secondary loop description

The secondary loop consists of H_2SO_4 feed pump, evaporator, PHE, separator, SO_2 trap and etc. The SO_3 and H_2O decomposed from H_2SO_4 flow in the secondary loop as a gas, and its flowrate is controlled by a flow controller. The SO_3 is decomposed into SO_2 and O_2 in the PHE. The mixture of SO_2, O_2, and unreacted 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 PHE in the secondary loop side are ;

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

3. Determination of sulfuric acid flowrate

In PHE, gaseous sulfur trioxide receives heat from the primary nitrogen gas and decomposes into gaseous sulfur dioxide and oxygen. The heat equal to 10 kW transfers from nitrogen gas to gaseous sulfur trioxide.

If we assume the decomposition ratio of SO_3 at 825℃ is around 0.8[3], 1 mole of feed sulfuric acid results in the gas mixture of 0.8 mole sulfur dioxide, 0.4mole oxygen , 1 mole water vapor and 0.2mole sulfur trioxide. The heat supplied from nitrogen gas is equal to the heat for sulfur trioxide decomposition plus heat needed to raise the gas mixture temperature.

3.1 Heat of reaction

1) Heat of reaction at 25 ℃ and 1.0 bar

Sulfur trioxide decomposes into SO_2 and O_2 as follows:

$$SO_3\ (g) \rightarrow SO_2\ (g) + 1/2\ O_2\ (g)$$

The simple calculation shows the standard heat of formation for the above reaction is 98.89 kJ/mole. [4]

2) Heat of reaction at 825 ℃, 40 bar

Neglecting pressure effect, the heat of reaction at 825℃, 1bar is calculated by the below equation. [4]

$$\Delta H^o = \Delta H_o^{\ o} + R\int_{T_o}^{T} \frac{\Delta C_p^{\ o}}{R} dT$$

,where ΔH^o and $\Delta H_o^{\ o}$ are enthalpy of reaction at temperature T and T0, respectively. Calculation shows the heat of reaction at 825 ℃, 40 bar is equal to 97.11 kJ/mole.

Based on 1 kg/min of sulfuric acid, the total heat of reaction for sulfur trioxide decomposition (Qrxn) is calculated as

Qrxn = ṁ X Q (enthalpy of reaction)
= 0.17 mol/sec SO3 X 97.11 kJ/mole
= 16.51 kW

Since decomposition rate of SO3 is 0.8, the necessary heat for the decomposition reaction is

Δ Hrxn = 16.51kW X 0.8 = 13.2 kW

3. 2 Heat to raise the temperature of the gas mixture

Heat to raise the temperature of the gas mixture is calculated as

$Q_{mix} = \dot{m} C_p \Delta T$ = 7.89 kW

, where $\dot{m}$ = 0.408 mol/sec,
$C_{p,mixture}$ =48,317 J/kmol-K ,
ΔT = 400K

3.3 Determination of sulfuric acid flowrate

When the sulfuric acid flowrate is 1.0 kg/min, 13.2 kW of heat is used to disintegrate sulfur trioxide and 7.89 kW is used to raise the temperature of gas mixture from 500 ℃ to 900 ℃.

Same calculation has been repeated with sulfuric acid flowrate changes until the total heat is equal to 10kW, and the result shows in case of sulfuric acid flow-rate of 0.5 kg/min, 6.6kW of heat is used to disintegrate sulfur trioxide and another 3.9kW is used to raise the temperature of gas mixture from 500 ℃ to 900 ℃.

Hence the flowrate of sulfuric acid should be greater than 0.5 kg/min to extract heat more than 10 kW from PHE.

4. Sulfuric acid flowrate determined by simulator

The simulation flowsheet is shown in Figure 2.

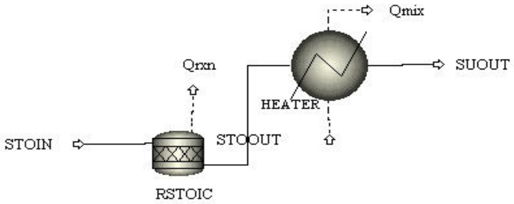

Figure 2. Simulation results for PHE in the small-scale test loop

The simulation result, when sulfuric acid flowrate is 0.4772 kg/min , is shown in Table 1.

Table 1. The simulation result in case of 0.4772 kg/min of sulfuric acid flowrate

	STOIN	STOOUT	SAOUT
Mole Flow mol/se			
H2O	0.0811454	0.0811454	0.0811454
SO3	0.0811454	0.016229	0.016229
SO2	0	0.0649163	0.0649163
O2	0	0.0324581	0.0324581
Mole Frac			
H2O	0.5	0.4166667	0.4166667
SO3	0.5	0.0833333	0.0833333
SO2	0	0.3333333	0.3333333
O2	0	0.1666667	0.1666667
Total Flow mol/sec	0.1622909	0.194749	0.194749
Total Flow gm/sec	7.958702	7.958702	7.958702
Total Flow l/sec	10.42251	12.51181	18.99458
Temperature C	500	500	900
Pressure bar	1	1	1
Qrxn kW	6.29442995		
Qmix kW	3.70557005		

Table 1 shows that 6.2944 kW of heat is used to disintegrate sulfur trioxide and the other 3.7056 kW is used to raise the temperature of gas mixture from 500 ℃ to 900 ℃.

5. Summary

The small scale high temperature test loop(10kW) was designed conceptually to simulate sulfuric acid decomposition process of SI cycle with VHTR operational conditions, 950 °C and 4 MPa.

In case of sulfuric acid flow-rate of 0.5kg/min, 6.6kW of heat is used to disintegrate sulfur trioxide and the other 3.9kW is used to raise the temperature of gas mixture from 500 ℃ to 900 ℃. Hence the flow-rate of sulfuric acid should be greater than is 0.5 kg/min to extract heat more than 10kW from PHE.

ACKNOWLEDGEMENTS

This study has been carried out under the Nuclear R & D Program supported by the MOST of Korea.

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