Design of a Sulfuric Acid Super-Heating System for NHDD Simulated Loop

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1. Introduction

A small scale sulfuric acid loop that can simulate a part of the hydrogen production module of NHDD (Nuclear Hydrogen Development and Demonstration) is now under developing in Korea Atomic Energy Research Institute [1, 2]. A Sulfuric Acid Super-heating System (SASS) is a key component of sulfuric acid loop that will raise temperature of sulfuric acid up to 500°C before it enters a process heat exchanger (Figure 1).

The SASS components exposed to the serious corrosion environment in high-temperature sulfuric acid. Generally, corrosion proof materials like a glass or quartz have week and brittle characteristics that are not appropriate high pressure application. While Teflon coating or glass lining on the carbon steel allows sulfuric acid to heat at a high pressure, they have temperature limit to use (Teflon coating ~160°C, glass lining ~230°C). Some kinds of super-alloys have the good corrosion characteristics up to 120°C in sulfuric acid. In this study, we discussed an effective design method of a corrosion proof sulfuric acid super-heating system heating sulfuric acid up to 500°C.

2. Design analyses

2.1 Sulfuric acid loop

Main usage of the sulfuric acid loop is to screen the candidates for the nuclear hydrogen coupled components, a SO_3 decomposer and a sulfuric acid evaporator in high-pressure and high-temperature condition. A sulfuric acid (H_2SO_4) loop is an open loop and consists of a H_2SO_4 storage tank, a H_2SO_4 feed pump, a pre-heater, a heat exchanger (evaporator), a PHE, a separator, a SO_2 trap, and a H_2SO_4 collector (Figure 1). Cold 98% H_2SO_4 is superheated to 500°C. In a superheating process, H_2SO_4 decomposes into H_2SO_4 and SO_3. In the PHE, some fraction of SO_3 is dissolved into SO_3 and O_2. The toxic SO_3 are separated in the separator and the sulfur dioxide in the mixture gas is removed in the NaOH trapping system. The design condition of the secondary loop is as follows;

- o Working Fluid — Sulfuric acid
- o Design Temperature — 950 °C
- o Design Pressure — 1.0 MPa.
- o Design Flow — 1.0 kg/min

2.2 Sulfuric acid super-heating system (SASS)

The SASS shown in Figure 1 is refined. It is composed of four components; a low-temperature pre-heater (LPH), a high-temperature pre-heater (HPH), an evaporator and a super-heater (Figure 2). The LPH uses corrosion free quartz as a heater element raising sulfuric acid up to 160°C manufactured by Watlow Gordon Co. (Figure 3a). This quartz heater has maximum 10kW power and can withstand fluid pressure up to

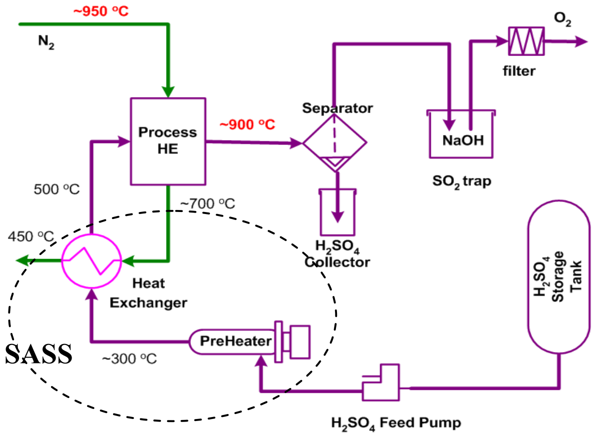


Figure 1 Schematics of a sulfuric acid loop

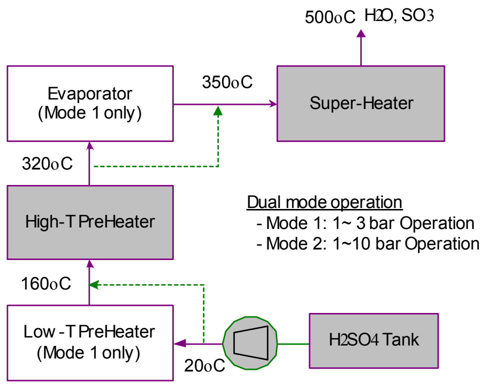


Figure 2 Sulfuric acid super-heating system (SASS)

0.5MPa. The HPH has U-shape SiC ceramic heaters with Hastelloy C276 vessel (Figure 3b). The HPM designed liquid sulfuric acid heat-up to 320°C by maximum power of 20kW. The evaporator is a commercial two-zone tube furnace of 11kW as shown in Figure 3d which is evaporating and slightly super-heating the saturated sulfuric acid supplied by HPM. The super-heater raising sulfuric acid gas up to 500°C is designed with special care against corrosion by high-temperature sulfuric acid gas. It composed of SiC ceramic heater elements, internal insulator, alumina liner and Hastelloy C276 vessel (Figure 3c). The specification of a sulfuric acid heating system is as following;

Pressure,	< 1.0 MPa
Inlet/outlet temperature,	20/500 °C
Flow rate,	< 0.5 kg/min

The SASS has two operational modes, low-pressure operation mode and high-pressure operation mode as shown in Figure 2. In high-pressure operation mode, two quartz components (LPH & Evaporator) are isolated and HPH become an evaporator.

2.3 T/H analysis

The convection heat transfer in a tube has relatively simple relations if the flow condition is laminar. For laminar flow in a tube, Nusselt number can be derived to following value by an exact calculation [3];

$$Nu_d = \frac{hd_O}{k} = 4.364 \cdot \qquad (1)$$

In case of bundle geometry like the HPH or super-heater, the tube diameter in equation (1) can be replaced to the following hydraulic diameter.

$$d_h = 4\frac{A_{CX}}{P_W} \qquad (2)$$

For lower enriched sulfuric acid, the following heat-transfer coefficient is recommended [4, 5].

$$h_{SK} = \frac{h_{ID}}{B} \qquad (3)$$

Where $h_{ID} = 1/(x_1/h_1 + x_2/h_2)$

$B = (1 + A_0|y_1 - x_1|0.88 + 0.12P)$

x_1, y_1: mole fraction of liquid water and steam
x_2: mole fraction of liquid H_2SO_4
h_1: Heat transfer coefficient of water
P: Pressure

The design calculation of SASS components carried out at atmosphere. It is very conservative approach in designing the evaporator and the super-heater because the mixture density will be increase with pressure; the components become larger.

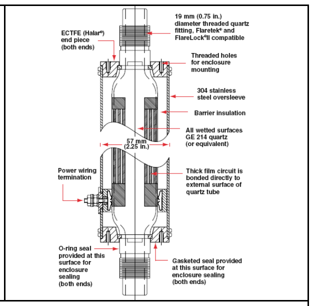
2.4 Design requirements

The maximum operating temperature of the SiC or quarts heater elements is over 1500°C, but we limited maximum operating temperature of the heaters in components design lower than 1200°C in considering enough operation margin. Super-alloy C276 is adopted the vessel of super-heater because it has good corrosion resistivity up to 120°C in sulfuric acid. Vessel of super-heater is insulated by thick ceramic fiber insulator to retain the vessel temperature below 120°C. The HPH vessel thickness should be chosen at least one level higher than normal pressure degree in considering corrosion loss of vessel internal surface. We designed schedule 40 grade seamless pipe. All the SASS components are remote controlled in control room.

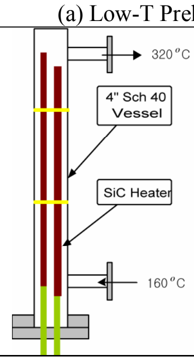
3. Conclusion

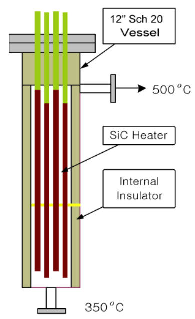
We designed a corrosion proof sulfuric acid super-heating system (SASS) for NHDD simulated sulfuric acid loop. We figure out the following results for designing the SASS system;

1. The primary concern of a SASS is to prevent sulfuric acid corrosion.
2. Quartz heater has good corrosion resistivity but not suitable in high pressure application.
3. Corrosion proof high-temperature super-heater is designed by combination of Hastelloy C276 and internal insulator to raise the outlet temperature up to 500°C
4. The vessel of high-pressure heater inevitable from sulfuric acid induced corrosion. The thicken vessel should be adopted to prolong the vessel life.

(a) Low-T Preheater (Watlow Gordon Co.)





(b) High-T Preheater (c) Super-Heater

- Indirect heating by using Two-zone SiC heater
- Quartz flow path
- Tin = 320°C
- Tout = 350°C

(d) Evaporator (Linberg/Blue Co.)

Figure 3 Layout of SASS components

5. Dual operation mode of SASS reduces the volume of corrosion damaged components and gives broad experimental condition.

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