Preliminary Experiment of a High-Temperature Sulfuric Acid Loop for NHDD Components Test

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1. Introduction

Hydrogen energy needs are growing these days with increased demands for alternatives to fossil fuel. Hydrogen has attracted a lot of interest as a clean energy due to environmental issues such as global warming and depletion of fossil fuels.

Recently, many countries have been actively developing massive hydrogen production systems by using nuclear energy which can supply large amounts of energy without carbon dioxide. A study of a Nuclear Hydrogen Development and Demonstration (NHDD) Plant has been developed during the last 3 years in Korea [1].

Very High Temperature gas cooled nuclear Reactor (VHTR) is a best candidate of nuclear hydrogen production as an efficient production of hydrogen.

Among the various hydrogen production methods such as a Sulfur-Iodine (SI) thermo-chemical cycle, a water splitting cycle, a high temperature electrolysis, and a hybrid sulfur cycle etc, SI cycle is adopted as a hydrogen production module that will be connected to VHTR.

To simulate a H_2SO_4 decomposition part of SI cycle, we designed and manufactured a high-temperature and high-pressure sulfuric acid loop [2]. The primary objective of the loop is to validate the corrosion and the mechanical performances of a key component of the NHDD, Process Heat Exchanger (PHE). In this paper, we discussed experimental results of the sulfuric acid loop. Also, the various features and performance the tests of each component are obtained.

2. Methods and Results

2.1 Sulfuric Acid Loop

A sulfuric acid (H_2SO_4) loop at KAERI consists of a H_2SO_4 storage tank, a H_2SO_4 feed pump, a sulfuric acid evaporator (or pre-heater) and sulfuric acid decomposer (or super-heater), a process heat exchanger (PHE), a high temperature cooler (condenser), a separator, a SO_2 trap, a low temperature cooler, and a H_2SO_4 collector as shown in Figure 1 [2]. Liquid sulfuric acid of room temperature is supplied from a H_2SO_4 storage tank via pump to an evaporator. Liquid sulfuric acid via evaporator and decomposer is heated up to 500°C. The evaporated sulfuric acid is decomposed into water vapor and sulfa trioxide in the decomposer. The sulfa trioxide is dissolved into SO_2 and O_2 in a PHE by a heat from nitrogen gas of the primary loop. The emitted gases at the PHE outlet are a mixed gas with SO_3, SO_2, H_2O, O_2. On the way the mixed gas passes through the cooler and the separator, the sulfur trioxide gas reacts on water vapor and become liquid sulfuric acid. Liquid sulfuric acid passes through the low temperature cooler and drains in the sulfuric acid collector. SO_2 and O_2 in the separator flow into the SO_2 trap system. Finally, the O_2 is released to the atmosphere.

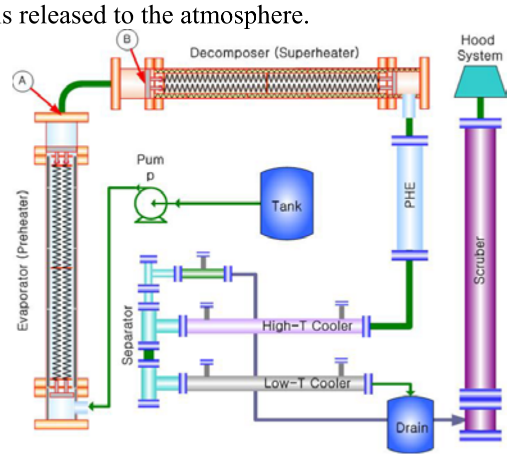

Fig. 1. Schematic Diagram of Sulfuric Acid Loop Facility

2.2 Experiments

The experiments of sulfuric acid loop were performed in open loop. The inlet temperature of sulfuric acid is room temperature and pressure is atmosphere. The working fluid is H_2SO_4 with 96 wt%. Maximum temperature of heater surface is increased up to 800 °C. Mass flow of sulfuric acid is 8cc/min and total experiment operation time is 10 hours.

2.3 Test Results

Figure 2 and 3 show the temperature trends of loop components and wire-heater (evaporator and H_2SO_4 decomposer). The marked point of figures is a position of the power change. The power was increased at the point 1 and 3. The power was decreased at the point 2 and 4. As the increase of the power at point 1, outlet temperature of decomposer decreases as shown in Figure 2. Also, point 3 was similar to point 1. However, as the decrease of the power at point 2 and 4 due to large temperature difference between heater and tube, outlet temperature of decomposer was increased. For the analysis of the decomposer, simple numerical computation was applied [3]. Figure 4 shows the temperature and decomposition rate profiles of the decomposer between point 1 and point 2 marked in Figure 2. As the power was increased, the outlet temperature of decomposer was decreased as shown in figure 4(a). The reason of these behaviors was due to the increase of the decomposition rate as shown in Figure 4(b). In decomposition, even if the power was increased, such as point 1 and 3, the outlet temperature of decomposer was decreased. The effect of decomposition is larger than the effect of the increased power.

Figure 5 shows the plenum after experiment of sulfuric acid loop. Liquid sulfuric acid of high temperature passes through the point A in Figure 1. At the lower part of the point B in Figure 1, Liquid sulfuric acid of high temperature flow into the decomposer. At the upper part of the point B, sulfuric acid vapor of high temperature flow into the decomposer. The Hastelloy C-276 plenum after experiment indicates that the severe corrosion did not occur under operation conditions of the present experiment.

3. Conclusions

A high temperature sulfuric acid loop is simulated for the validation of the NHDD components. We obtained the following results for the preliminary experiment of the high temperature sulfuric acid loop.

1. On the way of temperature rising operation of the loop, we found an outlet temperature decreasing phenomenon in the H_2SO_4 decomposer in spite of raising the power of decomposer continuously (Point 1 and 2 in Figure 2 and 3). The reason of this phenomenon is due to the heat sink by an endothermic reaction on the H_2SO_4 decomposition process
2. After experiment, a serious corrosion problem is not happened in the Hastelloy C-276 plenum

ACKNOWLEDGMENTS

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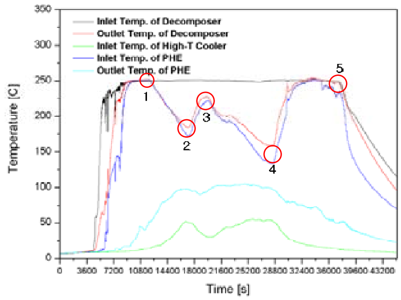


Fig. 2. Temperature Trends of Loop Components

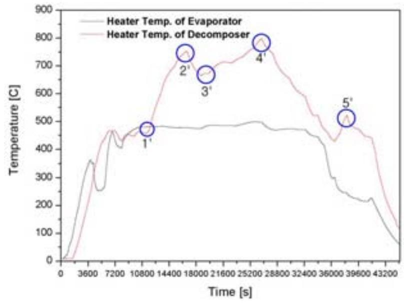
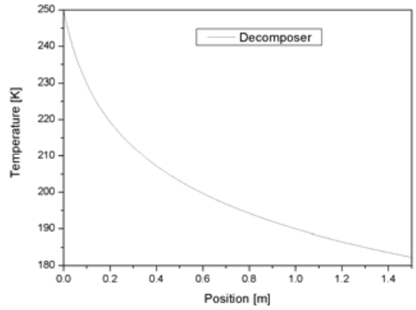
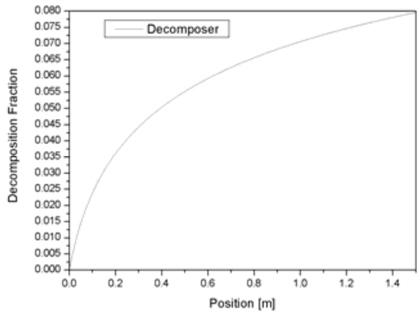


Fig. 3. Temperature Trends of Wire Heaters (Evaporator and H_2SO_4 Decomposer)



(a) Temperature



(b) Decomposition rate

Fig. 4. The Temperature and Decomposition Rate Profiles of the Decomposer between Point 1 and Point 2 marked in Figure 2


(a) Point A (b) Point B
Fig. 5. Picture of the Plenums after Sulfuric Acid Experiment