Pressure Drop of Hybrid Heat Exchanger for SO_3 Decomposition

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1. Introduction

A sulfur trioxide decomposer is one of the main technical challenges in the development of a nuclear hydrogen production system using SI cycle or hybrid sulfur cycle. Kim et al.[1] developed a hybrid heat exchanger for the sulfur trioxide decomposition to withstand its severe operating conditions. The operation conditions include the high temperature over 850 ^{o}C, the large pressure difference over 1 MPa, and the corrosive working fluid with the sulfuric acid gas mixture. The surface contacted with the process gas is coated with the corrosion resistant silicon carbide. Ion beam mixing technology with nitrogen ions is applied to reduce the thermal stress through the mixed interface between the coating layer and the base material [2]. The base material of the heat exchanger is heat-resistant super alloy such as Hastelloy X. The hot gas channel plate and the process gas channel plate are joined by Park et al.'s diffusion bonding process [3]. Kim et al. [4] performed the sensitivity analysis of the thermo-chemical design of the hybrid-concept sulfur trioxide decomposer to determine the operation condition of the laboratory-scale decomposer. The feasibility test results of the heat exchanger showed the surface enhancement effect on the corrosion-resistance in the sulfuric acid gas condition [5]. Song et al. [6] provided the thermal-structural analysis results to install the laboratory-scale heat exchanger to maintain the structural integrity at the experimental condition. In this study, we obtained the experimental results for the pressure drop of the laboratory-scale hybrid heat exchanger.

2. Experimental Setup

In this section, the description of the experimental setup is focused on the laboratory-scale hybrid heat exchanger and its installation in the gas loop. The gas loop was explained in Kim et al. [5].

Figure 1 shows the drawing for the cross-sectional view of the laboratory-scale hybrid heat exchanger. The hot gas channel side has semicircular channels similar to a printed circuit heat exchanger because of robustness to withstand the large differential pressure between the hot gas side and the process gas side. The process gas side has sine-shape channel like a plate-fin heat exchanger. The channel size is large enough to install and substitute the ball-type catalyst for acceleration of the sulfur trioxide. The surface contacted with the sulfuric acid gas is modified by ion-beam mixing and silicon carbide coating technologies. The length and the width of the effective heat transferred region is 0.15 m $\times$ 0.15 m due to the limits of the ion-beam mixing chamber size. The number of each channel stacks is 10.

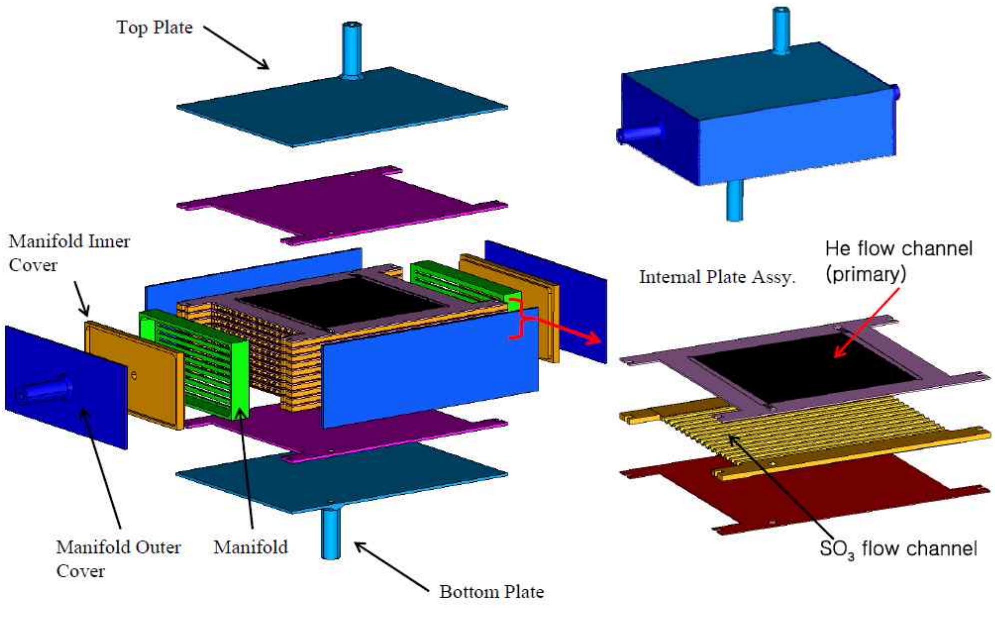

Figure 1 Drawing of Hybrid Heat Exchanger [6]

Figure 2 shows the picture of the installation of the hybrid heat exchanger in the small-scale gas loop. The small scale-gas loop was in-detail explained in Kim et al. [5]. Song et al. [6]'s analytical results showed that the thermal stress due to the temperature gradient is very important to maintain the structural integrity of the hybrid heat exchanger. So, the U-shape tube was installed in the inlet of the hot gas side to reduce the thermal expansion effect from the high temperature condition.

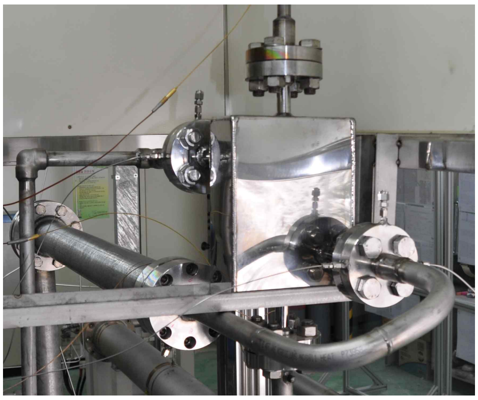

Figure 2 Installation of Hybrid Heat Exchanger

3. Results & Discussion

Figure 3 shows that the most of the pressure drop in the process heat exchanger results from the form loss of the inlet and the outlet. The pressure drop of the hybrid heat exchanger is about 95% of the bypass pressure drop. As shown in Figure 1, the hot gas channels stack shape is not the same as the general shape of the printed circuit heat exchanger. The shape of Figure 1 is to obtain the maximum area of the effective heat transfer region and the simple diffusion bonding process. The shape and flow area of the inlet and outlet plenum of the hybrid heat exchanger has to be optimized to minimize the pressure drop of the hot gas side.

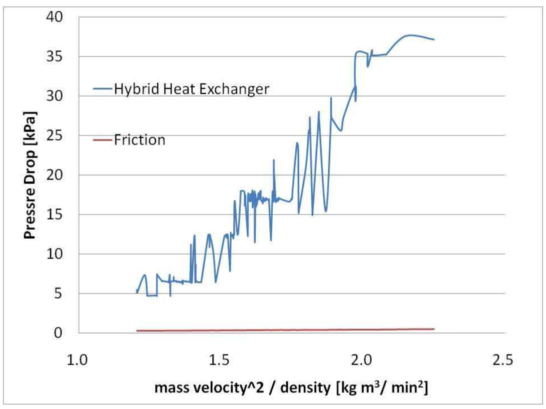

Figure 3 Pressure Drop in Hybrid Heat Exchanger

Generally, the hybrid heat exchanger concept has the crossflow design to facilitate the diffusion bonding process. But the maximized SO_3 decomposition requires the counter-current design heat exchanger due to high reaction temperature. The stack of the hot gas side is similar to that of the general PCHE. The parallelogram is selected as a channel plate shape of the effective the process gas side. The plenums of the hot gas side must be optimized to increase the flow velocity in the outlet of the process gas.

4. Conclusion and Future Works

Experimental results showed that the hot gas pressure drop of the hybrid heat exchanger was too high to obtain the enough velocity to simulate the high temperature condition above 900℃. The form loss of the inlet and the outlet of the hot gas side had the most fraction of the total pressure drop of the laboratory-scale hybrid heat exchanger. The stack shapes of the hot gas and the process gas sides will be optimized to minimize the pressure drop, maintain the counter-current type, and facilitate the diffusion bonding process.

ACKNOWLEDGMENTS

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