Operation Experiences of the Small Scale Nitrogen Loop with a Water-Cooling Printed Circuit Heat Exchanger

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1. Introduction

A small scale nitrogen loop [1] is in-operation for the integrity and feasibility test of the hybrid-concept sulfur trioxide decomposer [2]. The small-scale gas loop takes the place of the hot gas and the process gas loop. The hot gas loop simulates the intermediate loop of a nuclear hydrogen production system in that it is designed to withstand the maximum temperature of 1273K, the maximum pressure of 6.0 MPa, and to operate at a mass flow rate of 2.0 kg/min with 4.0 MPa. Nitrogen is used as the working fluid for simple high pressure gas experiments. The fluid temperature is controlled by adjusting the power of the heaters using direct voltage controllers. The accumulator maintains the primary system at the constant pressure. The inverter of the circulator and the bypass flow valve control the primary mass flow rate.

In this paper, the operating experience is presented to estimate the performance of the primary system as Figure 1. A water-cooling printed circuit heat exchanger [3] was used to cool the hot gas into the room temperature.

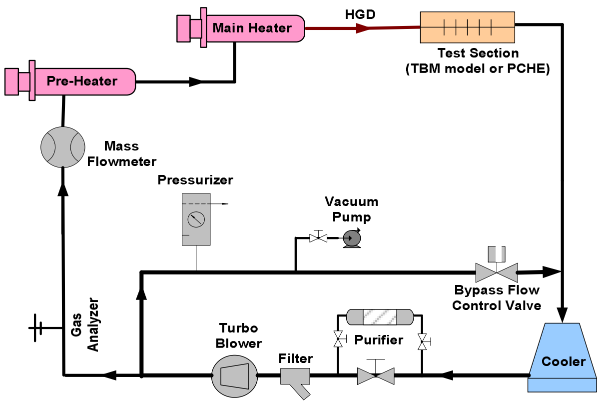

Figure 1 Schematic Diagram of the Nitrogen Loop with a Water Cooled PCHE

2. Description of a Small Scale Nitrogen Loop

In this section, the description of the nitrogen loop is focused on the water-cooled printed circuit heat exchanger and the measurement of the various thermo-hydraulic behaviors including the power, the pressure, the mass flow rate and the temperature in the loop.

2.1Pressure and Differential Pressure

To measure the pressure in the gas loop is relatively easier than any other properties. The pressure and the differential pressure were measured at the inlet of the preheater through the scalable pressure transmitters produced by the Rosemount Incorporation. The measured position of the pressure was the inlet of the pre-heater and the accumulator. The differential pressure transmitters were installed at the inlet & outlet of the circulator and the bypass line.

2.2Mass Flow Rate

The mass flow rate of the primary system was measured through the U-tube Coriolis mass flow meter produced by Micro Motion. In a Coriolis mass flow meter, the "swing" is generated by vibrating the tubes in which the fluid flows. The flow velocity is determined from the swing angle, and the vibration frequency.

It was assumed that the most of the bypass line pressure drop is the form loss by the bypass flow control valve. Based on the preliminary cold test results with the fully opened bypass valve, the bypass mass flow rate can be calculated from the bypass valve constant and the pressure drop at the bypass line as the following equation.

$$\left(\Delta p_{bypass}[bar]\right)^{0.5} = 0.148\frac{W_{bypass}[kg/\min]}{\left(\rho[kg/m^3]\right)^{0.5}} \quad (1)$$

The total flow rate of the loop is the sum of the measured primary mass flow rate and the calculated bypass mass flow rate. The pressure drop in the cooler and the filter can be obtained from the total pressure drop and the bypass line pressure drop. The cold test results gave us the following relation with the total mass flow rate the pressure drop between the inlets of the cooler and the circulator.

$$\frac{\left(\Delta p_{tot} - \Delta p_{bypass}\right)}{3600} = C\frac{(W_{bypass} + W_{main})^2}{\rho} \quad (2)$$

2.3Temperature

In this experimental loop, there are many K-type thermocouples to measure the temperature at the various positions. The thermocouples have the sheath diameter with 1/16 inch and the grounded junction for the fast response time. Especially, the thermocouples whose sheath diameter is 1/8 inch are installed at the hot gas positions. The radiation errors at the hot gas temperature measurement are corrected through the measured temperature difference between 1/16 inch and 1/8 inch thermocouples as the following equation [4].

2.4 Water-cooled Printed Circuit Heat Exchanger

A PCHE was installed to cool the hot gas above 1173K to the room temperature. So, one stack of the hot gas has two stacks of the water to obtain enough coolability at the high temperature inlet condition. The core dimension is 130 mm (W) × 220 mm (L) × 145 mm (H). The channel lengths of the effective heated region of the water side and the hot gas side are 0.185 m & 0.187 m, respectively. The material of the plate is stainless steel 316, because the plate temperature is very low for the heat transfer coefficient of water to be much higher than that of nitrogen.

3. Results & Discussion

Experimental results gave us the constant C of Eq. (2) with the various the square of mass flow rate over the density. C is 1.16053, of which standard deviation is ± 0.98 %. Experimental results, including the main mass flow rate and the pressure drops, were obtained at the various pressure and circulator rpm conditions.

Figures 2 and 3 show the histories of temperature, pressure drop and primary mass flow rate when the heater power was gradually increased in the nitrogen loop. Temperature rising increase the mass flow rate, pressure, and the pressure drop in the gas loop. When the outlet temperature of the high temperature heater was above 673K, the bypass line pressure drop was suddenly increased. In the contrary the primary mass flow rate was suddenly decreased. So, the opened fraction of bypass flow control valve was decreased to maintain the primary mass flow rate. At the inspection after the test, it was found that the oxide dust from the heaters blocked the flow channel of the PCHE. The large mass flow rate decreased the outlet temperature of the pre-heater. But the contrary linkage with the primary mass flow rate and the outlet temperature of high temperature heater resulted from the larger thermal loss effect than the temperature rising effect. The radiation-corrected temperature had a large oscillation at the outlet in the high temperature heater because of the oscillation of the measured temperature from a 1/16 inch thermocouple at the outlet.

4. Conclusion and Future Works

Experimental results show the good performance of the components of the gas loop. For the higher temperature, the dust control is required to prevent the sudden flow blockage of the PCHE. Flow baking procedure will be updated to remove the humidity of the thermal insulator in the heaters. In addition, GAMMA+ code will be used for the simulation of the temperature history at the experimental condition.

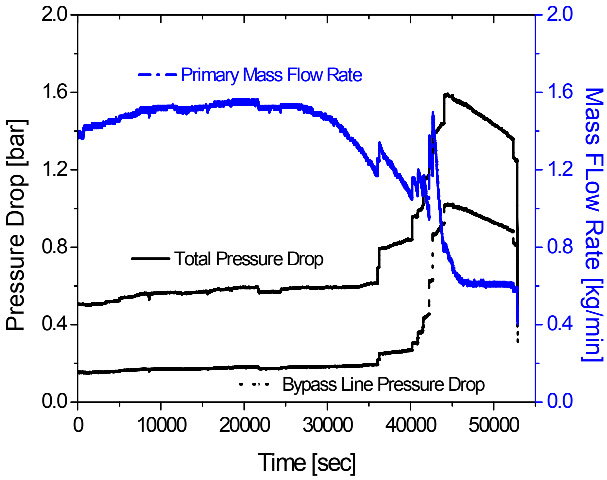

Figure 2 Constant C for the Total Mass Flow Rate

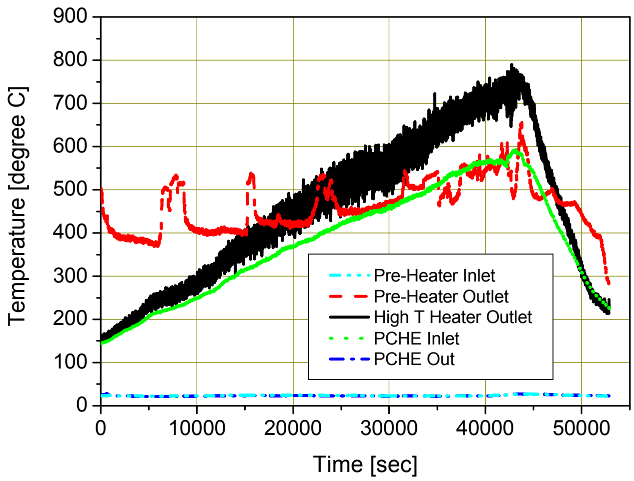

Figure 3 Temperature Histories

ACKNOWLEDGMENTS

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REFERENCES

[1] S. D. Hong et al.. Development of a Compact Nuclear Hydrogen Coupled Components Test Loop, ANS Embedded Topical Meeting, ST-NH2, Boston, MA, USA, 2007.
[2] Y. W. Kim et al., High Temperature and High Pressure Corrosion Resistant Process Heat Exchanger for Nuclear Hydrogen Production, ROK Patent 877574, 2008.
[3] S. D. Hong, Design and Manufacture of a Small-scale PCHE, Cal. Note, NHDD-KA-07-TL-003, 2007.
[4] C. S. Kim et al., Temperature Measurement with Radiation Correction for Very High Temperature Gas, IHTC-14-23074, 14th International Heat Transfer Conference, Washington, DC, 2010.