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A High Temperature Gas Loop to Simulate VHTR and Nuclear Hydrogen Production System

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1 ABSTRACT

The status of high temperature gas loop technology development has been presented in this paper. As a key technology development of nuclear hydrogen development and demonstration program in KAERI, a small scale nitrogen gas loop has been constructed from 2006. General layout and design feature of the gas loop and test scope have been discussed. A process heat exchanger was tested in this gas loop to confirm the validity of the concept. As a next step, 150kw Helium loop is being constructed from this year based on the small scale gas loop technology.

2 INTRODUCTION

Very high temperature gas cooled technology and nuclear hydrogen production technology are being developed in KAERI for the nuclear hydrogen production system as shown in Fig. 1 [Chang, J., et al., 2007]. The outlet temperature of the high temperature gas cooled reactor developed so far ranges 750 to 900^{o}C. However, to produce hydrogen with economical efficiency, the coolant outlet temperature outlet temperature of VHTR should exceed 950^{o}C. In this paper, a development of small scale gas loop to investigate coupling of the VHTR and hydrogen production system is introduced.

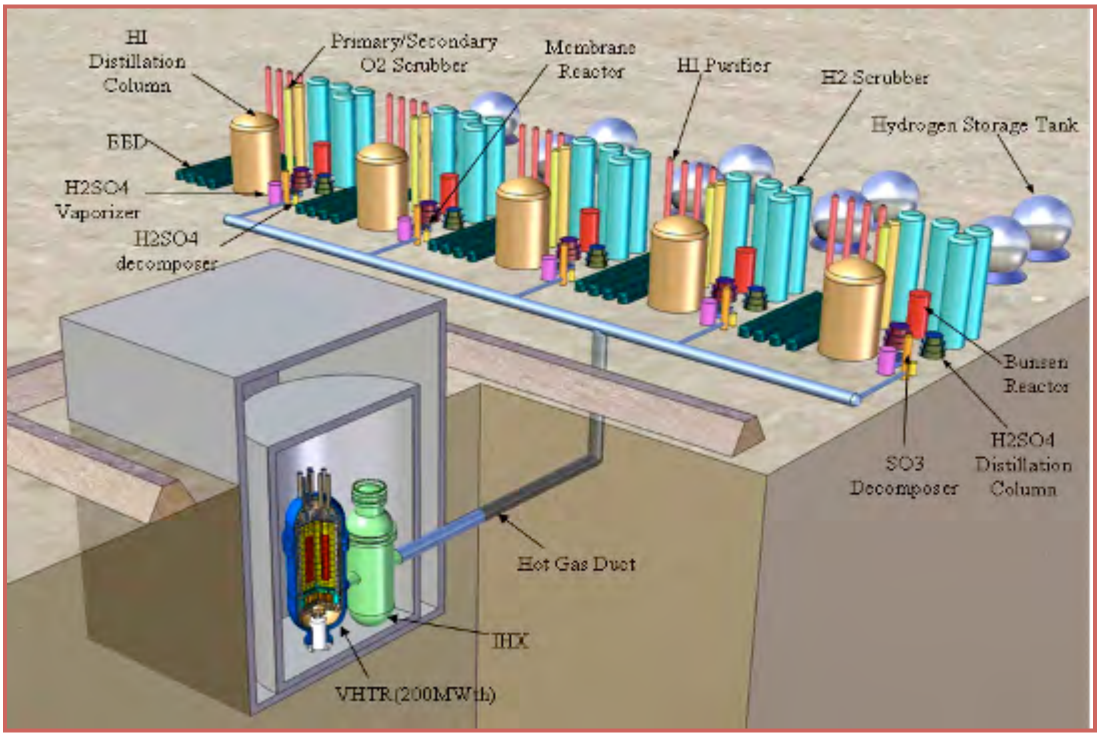

Fig. 1 Schematic layout of nuclear hydrogen production system.

A process heat exchanger developed which connects VHTR and hydrogen production system is tested in the gas loop. The whole process of gas loop development from the design to the construction is introduced. Also, some of the test result of heat exchanger structural integrity analysis and test is discussed.

3 NITROGEN GAS LOOP

Small gas loop has been developed in order to perform design concept test of process heat exchanger and to obtain high temperature experimental technology. The power at the test section of the gas loop is 10kw. Primary loop coolant is nitrogen and secondary coolant is sulfuric acid.

3.1 Primary Loop

The 3-D model and photo of the primary loop simulating VHTR heating system are shown in Fig. 2 and Fig. 3 respectively [Hong, S. D. 2008]. The design pressure and the design temperature of the primary loop are 6MPa and 1000^{o}C respectively. The process gas of the primary loop is nitrogen gas. Primary loop consists of pre-heater, main heater, hot gas duct, gas circulator with gas bearing, and isolation valves. Most of the pipe is thermally insulated to prevent over heating at the outer pipe structure.

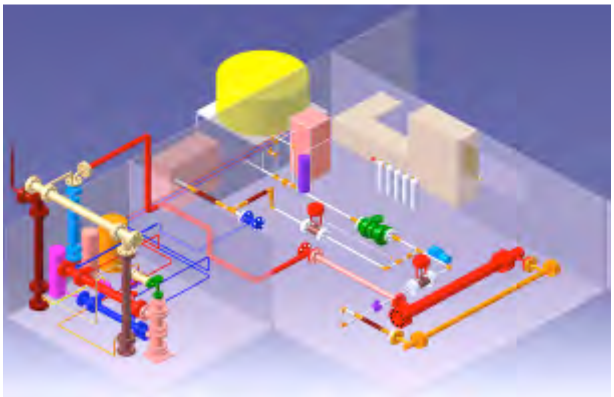

Fig.2 3-D model of 10kw gas loop

Fig.3 Photo of primary nitrogen loop

3.2 Secondary Loop

The secondary loop simulates the sulfuric acid hydrogen production process. As shown in Fig. 4, the 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. Cold 98% H_2SO_4 is superheated to 500°C.

As the acid passed over a process heat exchanger, SO_3, which is transferred heat from nitrogen gas of primary loop, is dissolved into SO_2 and O_2. The emitted gas from the process heat exchanger is a gas mixture with SO_3, SO_2, H_2O, O_2. Then, the mixed gas flow into the separator and sulfur trioxide in mixture gas combines with water vapor to form liquid sulfuric acid. Liquid sulfuric acid flows into the sulfuric acid collector. Sulfur dioxide in the gas mixture is trapped in the SO_2 trap system using NaOH solution. The oxygen, which occurs in the SO_2 trap system, is released to the atmosphere via filter system.

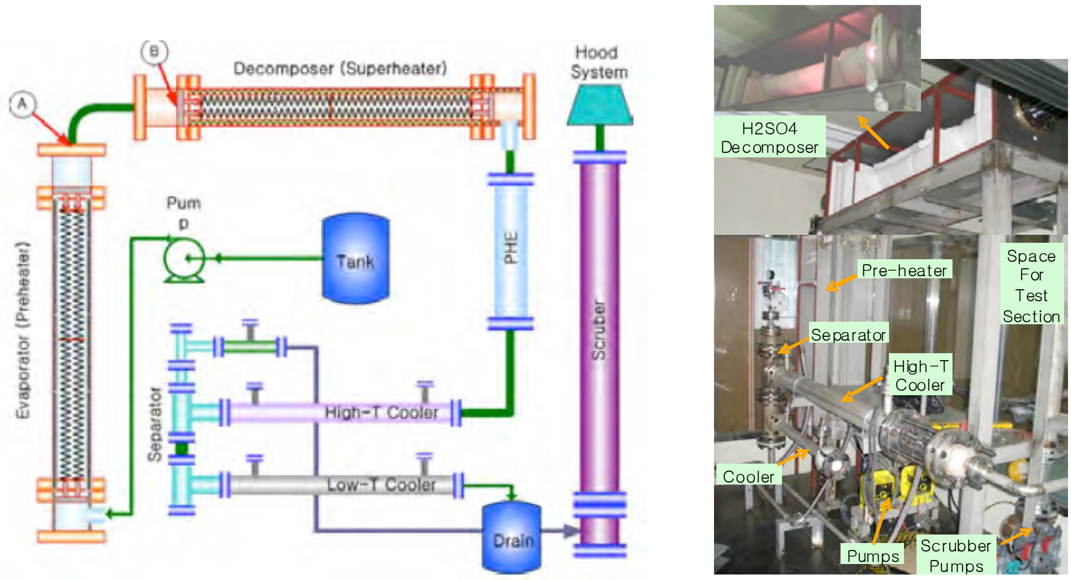

Fig. 4 Schematic drawing and photo of secondary loop

3.3 Process Heat Exchanger Test

Heat generated by the VHTR is transferred to the hydrogen production system via a process heat exchanger. One of the key components in the nuclear hydrogen production system is a process heat exchanger of the SO_3 decomposer which generates SO_2 gases at highly elevated temperature conditions. The helium gas flows in one side of the heat exchanger and sulfuric acid gas flows in the other side of the heat exchanger. The materials used for PHE require excellent mechanical properties at an elevated temperature as well as a high corrosion resistance in a SO_2/SO_3 environment. A ceramic heat exchanger with a strong corrosion resistance has difficulties for its manufacturing and thermal shock resistance points of view because of its low fracture toughness. KAERI has implemented the ion beam mixing surface modification technology to solve this technical problem[Kim, Y.W. et al., 2007]. The design requirement of the process heat exchanger is listed as four important items. First, the material of PHE should have enough corrosion resistance and high temperature strength. Second, PHE should withstand the pressure difference between a VHTR system and a hydrogen production system. Third, enough catalyst space should be available in the sulfur-gas side flow channel. Finally, it must be easy to manufacture.

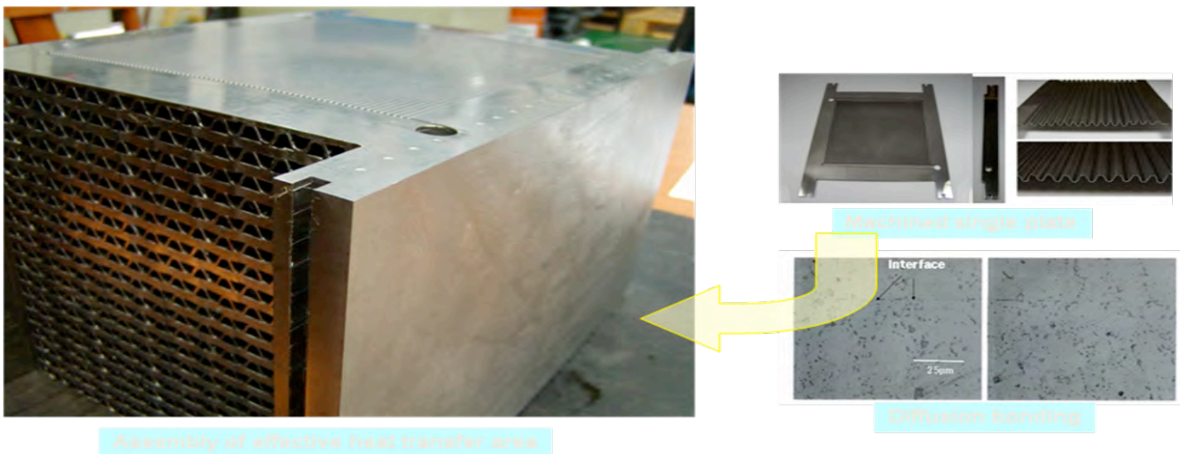

Fig.5 Process heat exchanger for the test in the gas loop.

In order to satisfy these technical requirements, a hybrid type PHE design was developed. As shown in Figure 5, the flow channel shapes of the He side and the sulfur gas side are different. The

He and the sulfur gas flow path have similar shapes to that of the printed circuit type heat exchanger and the plate fin type heat exchanger respectively. The design pressure of the present hybrid type heat exchanger is dominated by the He side high pressure. The flow channels for the sulfuric acid gas were coated with SiC and ion beam mixed to enhance their corrosion resistance [Park, J.W., 2008].

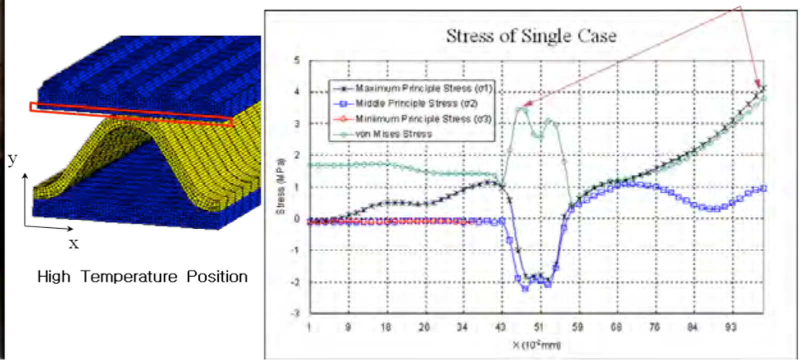

Fig. 6 Effect of ion beam mixing

Fig. 7 Stress analysis for process heat exchanger

As shown in Fig. 6, ion beam mixing has increased corrosion resistance considerably. Also, stress analysis has been performed to confirm the test in the test loop and it has been confirmed that PHE can withstand more than 15bar of pressure difference between primary and secondary loops.

4 HELIUM LOOP

Based upon the small scale nitrogen gas loop, 150kw Helium loop with helium purification system has been designed and is being constructed. Fig. 8 shows three-dimensional concepts of the designed helium loop. The construction of this loop will be finished in 2011.

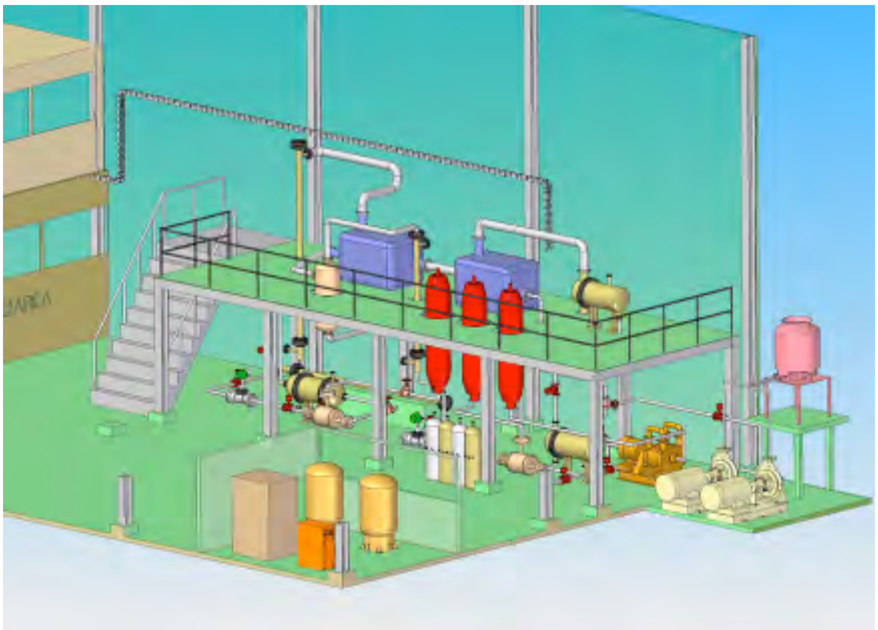

Fig. 8 3-D bird eye view of Helium loop under construction

5 CONCLUSION

A small scale nitrogen gas loop has been constructed from 2006 as a part of a key technology development of nuclear hydrogen development and demonstration program in KAERI. The construction of gas loop and the test performed have been discussed. A process heat exchanger was tested in this loop to con firm the validity of the concept. As a next step, 150kw Helium loop is being constructed from this year.

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