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Recent Research at KAERI for a Supercritical CO_2 Brayton ECS for a Gen-IV SFR

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1. Introduction

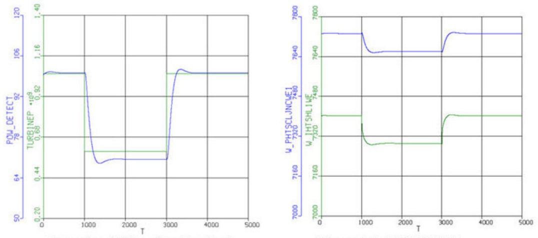
KAERI has conducted a systematic study for a supercritical carbon dioxide Brayton cycle energy conversion system coupled to the Gen-IV Sodium cooled Fast Reactor. A new configuration of a PCHE heat exchanger was developed by using a flow analysis, which shows a very small pressure loss compared with a previous PCHE while maintaining its heat transfer rate. A test apparatus was also installed to investigate a new PCHE performance. The MMS-LMR code was developed to analyze a system transient and control logic. On the basis of the code, the system behavior was analyzed when a turbine load was changed. Transient characteristics for the supercritical CO_2 Brayton cycle coupled with KALIMER-600 were also analyzed by using the developed computer codes. A Na-CO_2 chemical reaction test has also been conducting to investigate the fundamental reaction mechanism. This paper contains the current research overview of the supercritical CO_2 Brayton cycle ECS at KAERI.

2. System Transient Analysis and S-CO_2 Experiments

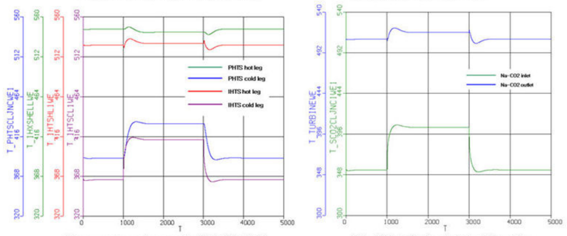
The MMS-LMR code was developed to analyze the transient phenomena in a SFR with a supercritical CO_2 Brayton cycle. A simple power/load reduction and recovery event was selected for the transient calculation. Then, the transient behavior was analyzed for the KALIMER-600 supercritical CO_2 Brayton cycle. Figure 1 shows transient analysis results.

For the evaluation of Na-CO_2 boundary failure event, a computer was also developed to simulate the complex thermodynamic behaviors coupled with the chemical reaction between liquid sodium and CO_2 gas. The long term behavior of a Na-CO_2 boundary failure event and its consequences which lead to a system pressure transient were evaluated for the shell-and-tube type Na-CO_2 heat exchanger of KALIMER-600 employing a supercritical CO_2 Brayton cycle. As depicted in Figure 2, the system pressure increases rapidly until the rupture disk break, and it promptly decreases to a pressure level higher than the normal operation mode.

For the verification of a Na-CO_2 chemical reaction model, KAERI has also conducted a serious of reaction test. Figure 3 shows the schematics of Na-CO_2 chemical reaction test apparatus, which is composed of two-types of test-section. One of test-section is installed to investigate a surface-reaction fundamental between Na and CO_2. The other is mounted to see the more real situation such as injection from CO_2 gas to the sodium. The surface reaction tests were recently conducted up to 600°C.



Power level (%) and turbine load
Flow rate in PHTS/IHTS



Temperature change in PHTS/IHTS
Na-CO_2 inlet/outlet in CO_2 side

Figure 1. Flow rate and temperature change in the PHTS/IHTS and the Na-CO_2 inlet/outlet in the S-CO_2 side for the transient operation

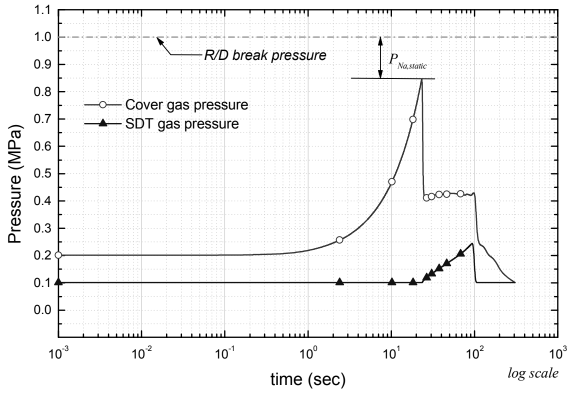


Figure 2. System pressure transient during the tube rupture event

To enhance the safeties and economics, various kinds of heat exchangers were investigated and the Printed Circuit Heat Exchanger^{TM} (PCHE^{TM}) was selected for the supercritical CO_2 Brayton cycle energy conversion system. For the evaluation of diffusion-bonded heat exchangers similar to PCHE models, a one-dimensional analysis computer code was developed to evaluate the performance of the heat exchangers and design data for the typical type PCHE was produced.

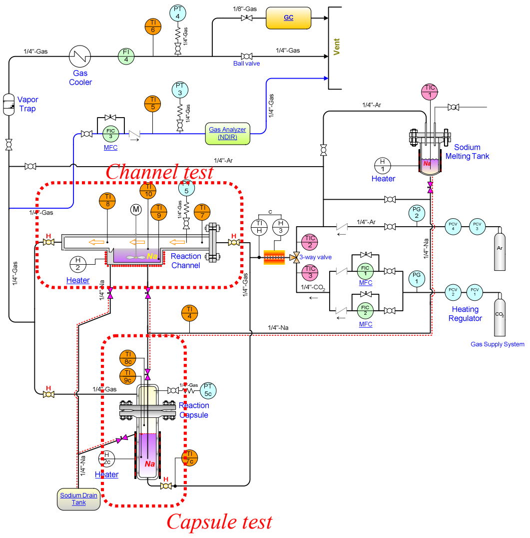


Figure 3. Flow diagram of Na-CO2 reaction test

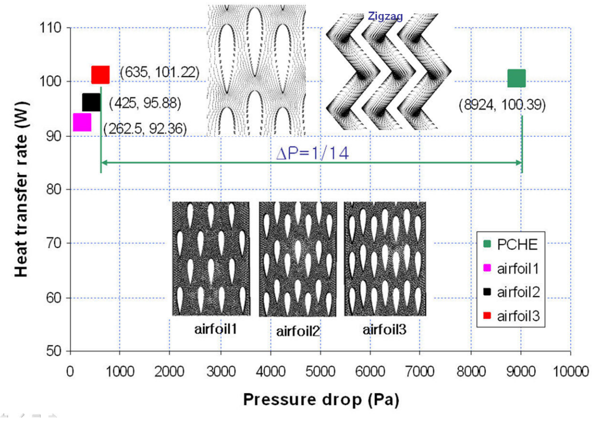


Figure 4. Performance of new configuration PCHE

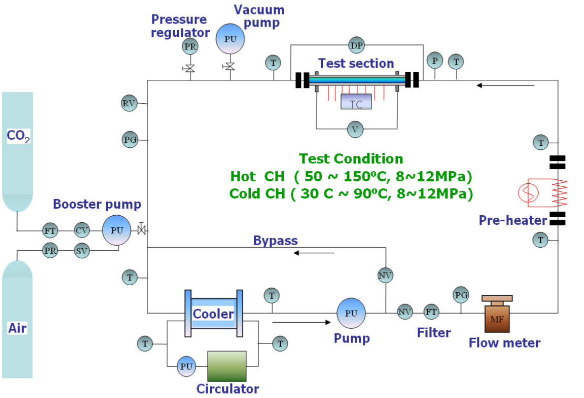


Figure 5. Schematics of S-CO_2 HEX Test Apparatus

In parallel with the PCHE-type heat exchanger design, a diffusion-bonded airfoil shape fin heat exchanger has been newly designed. The new design concept was evaluated by three-dimensional CFD analyses, which have showed that the airfoil shape fin heat exchangers conserves the total heat transfer rate and reduces the pressure drop by a factor of 14 (Figure 4). Figure 5 and Figure 6 show the HEX test apparatus to evaluate the performance of new PCHE. After then a preliminary test, the performance test has been recently conducted.

The two-types of PCHE test samples were made by diffusion bonding method with a 1mm thickness stainless steel SUS316. A total of nine etched HEX plate were bonded with a single banking layer. The depth of the channel etching is around 0.5mm.

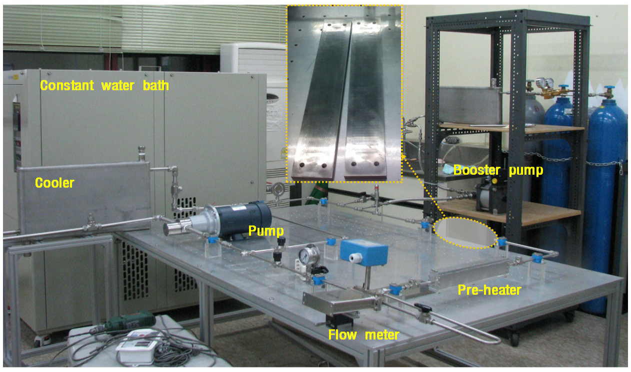


Figure 6. The S-CO_2 HEX Test Apparatus

3. Summary

A systematic research has been conducted to develop a supercritical carbon dioxide Brayton cycle energy conversion system coupled with a Gen-IV sodium-cooled fast reactor. The new airfoil shape PCHE was developed by using the CFD analysis, which has a 1/14 of pressure loss compared with the previous zigzag type PCHE while maintaining the heat transfer characteristics. Two experiments such as the Na-CO_2 chemical reaction and S-CO_2 PCHE performance test have been conducting for the S-CO_2 Brayton cycle development. The experiments will be finished within FY2009.

ACKNOWLEDGMENTS

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