Design and Flow Analysis of a Supercritical CO_2 Brayton ECS for KALIMER

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1. Introduction

The supercritical CO_2 Brayton cycle energy conversion system is presented as a promising alternative to the present Rankine cycle. The principal advantage of the S-CO_2 gas is a good efficiency at a modest temperature and a compact size of its components. The S-CO_2 Brayton cycle coupled to a SFR also excludes the possibilities of a SWR (Sodium-Water Reaction) which is a major safety-related event, so that the safety of a SFR can be improved. This paper describes a system control with a mass control valve and a flow analysis of the major components for the S-CO_2 Brayton cycle coupled to KALIMER-600.

2. ODP Analysis of S-CO_2 Brayton Cycle and Flow Analysis of Major Components

2.1 ODP Analysis of S-CO_2 Brayton cycle for KALIMER-600

For the development of the S-CO_2 Brayton cycle coupled to KALIMER-600, a thermal balance was established for 100% power operating conditions. The S-CO_2 Brayton cycle adopts two recuperators to increase its cycle efficiency and two compressors were adopted to avoid a sharp change of the physical properties near its critical point with a pressure. A thermal balance was calculated by an application of the cycle analysis code (RECOBA) developed by KAERI (Figure 1).

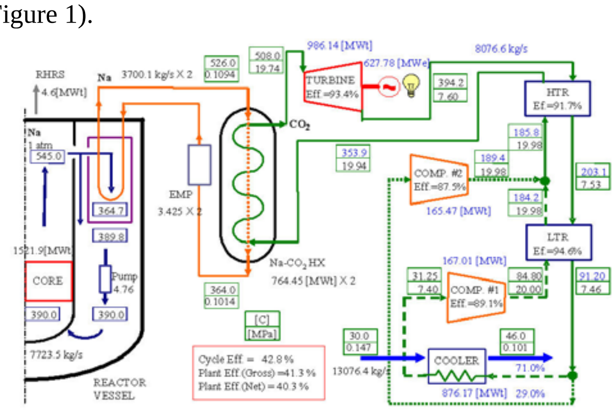

Figure 1. S-CO_2 Brayton cycle for KALIMER-600

On the basis of the results, we also developed a code to analyze the system behavior with several control actions such as a turbine bypass control, an inventory control, and a cooler inlet temperature control.

Figure 2 is the temperature-entropy diagram of the S-CO_2 Brayton cycle system coupled with KALIMER-600, which shows the system behavior by an opening of the flow control valve located in front of the turbine inlet. For the normal operation condition, the state properties which were calculated with the ODP analysis code are estimated within 1 % of those calculated with the RECOBA code for the steady cycle analysis. From this figure, we know that the S-CO_2 Brayton cycle can be controlled with the flow control action.

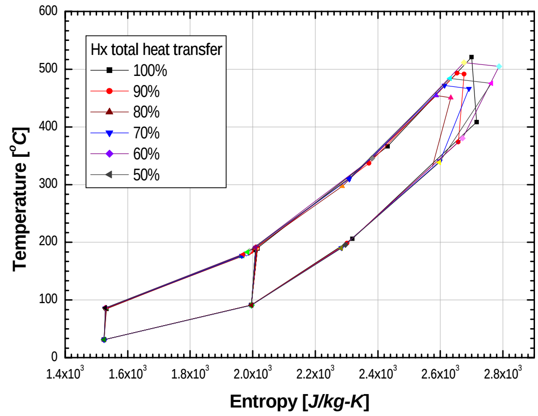

Figure 2. System control with mass flow rate

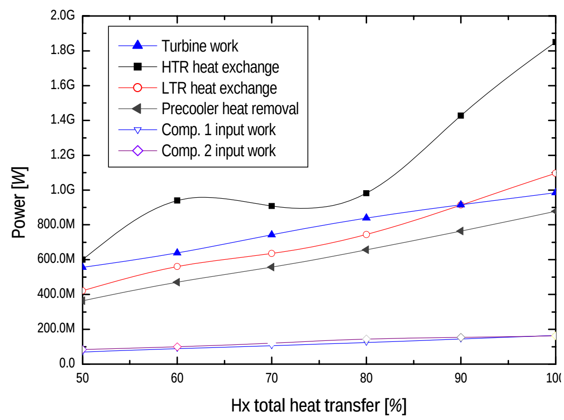

Figure 3. Power of each component with heat load

However, the flow control is not simple for the low flow rate under 40% of the heat exchange rate since the LMTD between the temperature of the HTR outlet and that of the LTR inlet is reversed. The efficiency inflection in the figure comes from the fluctuation of the heat transfer rate of LTR and HTR in Figure 3 which shows the behavior of the power of each component with the heat transfer rate of the Na-CO_2 HX. The heat transfer fluctuation of the LTR and HTR results from the split flow ratio and the characteristics of the compressor.

2.2 Flow Analysis of S-CO_2 Compressor

For the S-CO_2 energy conversion cycle's efficiency, the efficiency of the turbine and compressor is an important parameter. Since there is no practical experience or design data for the S-CO_2 turbomachinery, it is necessary to establish the methodologies for the design and performance analysis before the detailed design and manufacturing stage. Thus, one-dimensional codes for the turbomachinery have been developed continuously to design and to analyze their performance. To complement the codes, a three-dimensional flow analysis was conducted with the help of a commercial CFD code. In the case of a compressor design, a one-dimensional design and analysis code was developed to determine the compressor configuration parameter near an operation point on the basis of the meanline analysis method and a loss model. Using this code, a preliminary performance analysis of the compressor was conducted for the Kalimer-600 S-CO_2 Brayton cycle.

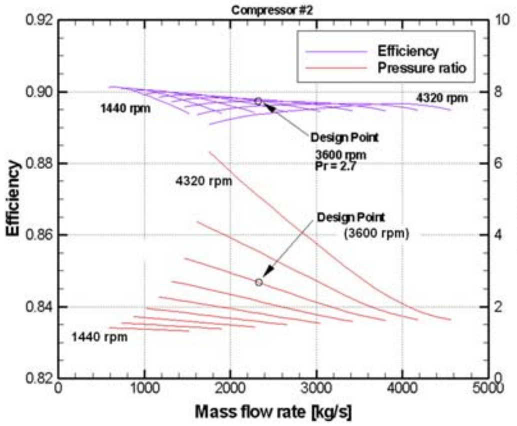

Figure 4. Performance of compressor #2 for the ODP

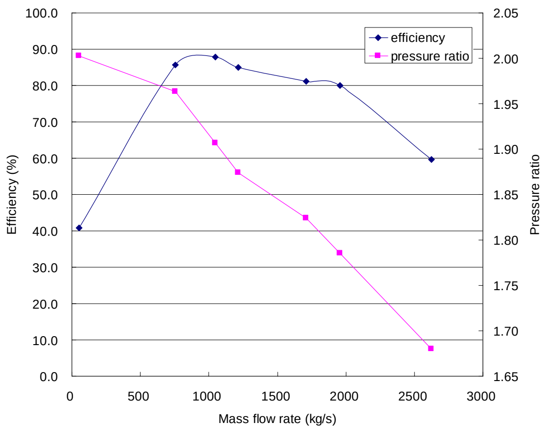

Figure 5. S-CO_2 compressor performance obtained through CFD flow analysis (compressor #2, 1st stage)

Figure 4 shows the off-design points (ODP) characteristics of the compressor #2 analyzed with the one-dimensional code (COMP1D). Figure 5 shows the ODP characteristics of the compressor #2 (1st stage) analyzed with the commercial CFX-11 code. A three dimensional configuration of the compressor was generated by ANSYS BladeGen™ on the basis of one-dimensional design properties. The two results are deviated to some extent. This is due to the lack of a loss model for the supercritical CO_2 compressor and a very complicated property change near by the critical point.

2.3 Flow Analysis of Compact Diffusion-Bonded Heat Exchanger

New configuration of the PCHE model was also developed by using a flow analysis with a commercial FLUENT code. New PCHE has an internal channel for an airfoil-fin configuration. It shows a very small pressure drop compared with a previous PCHE while maintaining the heat transfer rate (Figure 6). The reduction of the pressure drop in the airfoil shape fin PCHE model was caused by suppressing the generation of the separated flow owing to the streamlined shape of the airfoil fins.

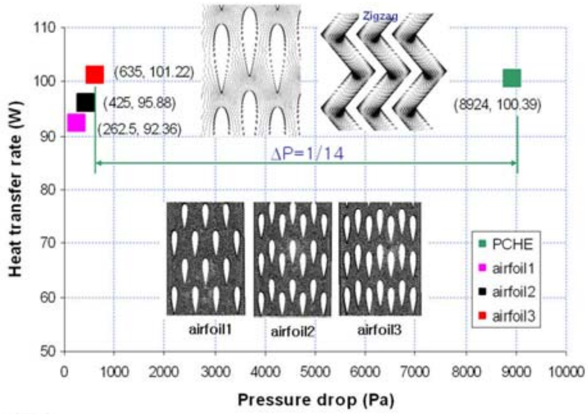

Figure 6. Performance of new configuration PCHE

3. Conclusions

The system behavior of a S-CO_2 Brayton cycle ECS was analyzed with a mass flow control action in front of the turbine inlet for KALIMER-600. The off-design characteristics of the S-CO_2 compressor 2 were investigated by using the commercial CFD code and the developed compressor design codes. The results are deviated to some extent. New configuration of the PCHE, which shows a very small pressure drop compared with a previous PCHE while maintaining the heat transfer rate, was developed by using a flow analysis with a commercial FLUENT code.

ACKNOWLEDGMENTS

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