Development of a Supercritical CO_2 Brayton Energy Conversion System for KALIMER

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1. Introduction

Recently, research on a power conversion cycle for a next generation reactor has been conducted and the Supercritical CO_2 Brayton cycle is presented as a promising alternative to the present Rankine cycle. The principal advantage of the S-CO_2 gas is a lower compression work compared to an ideal gas such as helium. As a result, a good efficiency at a modest temperature, a simplified compressor design and a compact size of the heat exchangers and turbines might be achieved. The S-CO_2 Brayton cycle coupled to a SFR also excludes the possibilities of a SWR (Sodium-Water Reaction) which is the major safety-related event, so that the safety of a SFR can be improved. This paper contains a description of the S-CO_2 Brayton cycle coupled to KALIMER-600.

2. Design of S-CO2 Brayton Cycle and Components

2.1 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 where all the reactor system models were included such as a primary heat transport system (PHTS), an intermediate heat transport system (IHTS), and an energy conversion system.

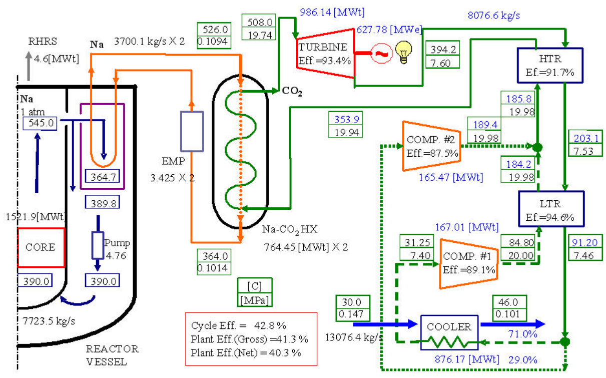

Figure 1. S-CO_2 Brayton cycle for KALIMER-600

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 developed by KAERI (Figure 1).

Considering the cycle efficiency and heat transfer area in the PCHE, the flow-split ratio is a major parameter for the system's efficiency and the LTR heat transfer area. From the investigation of the system efficiency and LTR area, the system efficiency reaches a maximum value at 69% of a split flow. However at this condition the LTR size is too large to implement. As the split flow ratio increases to 71%, the system efficiency decrease by 0.3% and the LTR area is reduced to an order of 1/10th. Based on this investigation, the optimum value of the split was determined as 71%.

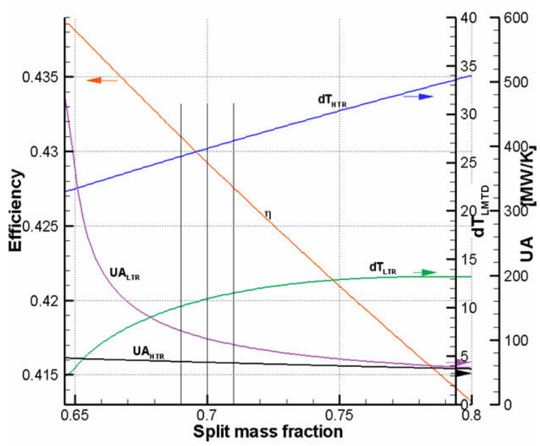

Figure 2. Flow-split ratio of a LTR downstream

2.2 Turbomachinery Design

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. The characteristics of the off-design points (ODP) were also analyzed with the code (Figure 3, Figure 4).

In the case of a turbine design, a one dimensional design code was developed to analyze the performance parameters. A methodology was also developed by using the commercial CFD code for the analysis of thermal hydraulics of the turbine. A three dimensional configuration of the turbomachinery was also generated by ANSYS BladeGen™ on the basis of one-dimensional design properties. From the CFD analysis, the mass flow rate was obtained as 8800 kg/s at 85 % of the isentropic efficiency (Figure 5).

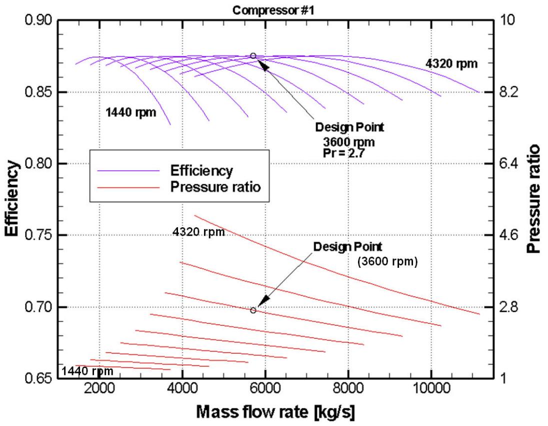

Figure 3. Performance of compressor #1 for the ODP

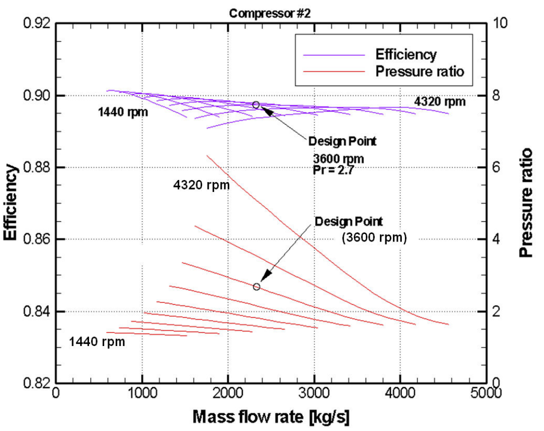

Figure 4. Performance of compressor #2 for the ODP

2.3 PCHE Design

The one-dimensional analysis code has been developed to evaluate the heat transfer performance and pressure drop characteristics of a Printed Circuit Heat Exchanger (PCHE). In order to assess the applicability of the developed model, the calculated results by the model were also compared with the existing experimental data.

As a first step to develop an improved design concept of the PCHE, a CFD analysis was performed to assess the applicability of the CFD method. New configuration PCHE model was 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).

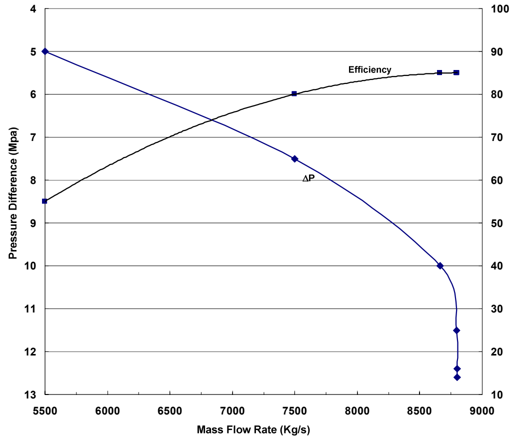

Figure 5. Performance of turbine for the ODP

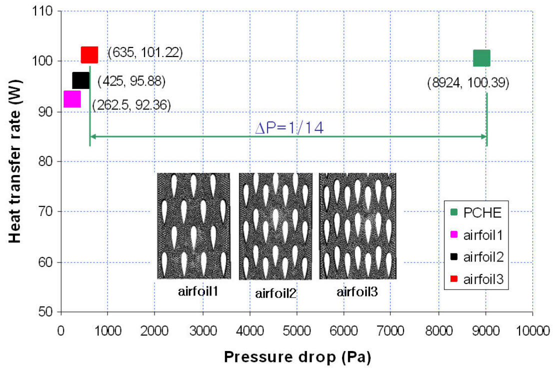

Figure 6. Performance of new configuration PCHE

3. Conclusions

A S-CO_2 Brayton cycle energy conversion system was constructed for KALIMER-600. Using the developed turbomachinery design codes, the off-design characteristics of the S-CO_2 turbomachinery were investigated. New configuration of 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.

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