Development of a Performance Analysis Code for the Off-design conditions of a S-CO_2 Brayton Cycle Energy Conversion System

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1. Introduction

For the development of a supercritical corbon dioxide (S-CO2) Brayton cycle energy conversion system coupled to KALIMER-600 [1], a thermal balance has been established on 100% power operating conditions including all the reactor system models such as a primary heat transport system (PHTS), an intermediate heat transport system (IHTS), and an energy conversion system. The S-CO2 Brayton cycle energy conversion system consists of a sodium-CO2 heat exchanger (Hx), turbine, high temperature recuperate (HTR), low temperature recuperate (LTR), precooler, compressor #1, and compressor #2. Two compressors were employed to avoid a sharp change of the physical properties near their critical point with a corresponding pressure. The component locations and their operating conditions are illustrated in Fig. 1[1].

Energy balance of the power conversion system in KALIMER-600 was designed with the full power condition of each component. Therefore, to predict the off-design conditions and to evaluate each component, an off-design performance analysis code should be accomplished.

An off-design performance analysis could be classified into overall system control logic and local system control logic. The former means that mass flow rate and power are controlled by valves, and the latter implies that a bypass or inventory control is an admitted system balance. The ultimate goal of this study is development of the overall system control logic.

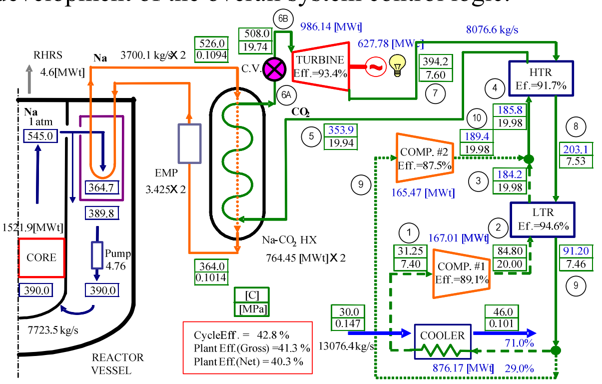

Fig. 1 S-CO_2 Braxton cycle for KALIMER-600

2. Methods and Results

The S-CO2 Brayton cycle analysis code has been developed with the following assumptions.

- ✓ Amount of heat exchanged from the Hx is regarded as an input value which is determined by the mass flow rate of a control valve opening.
- ✓ Pressure drop in the pipe lines are not considered.
- ✓ Amount of heat exchanged from the pre-cooler is proportional to the mass flow rate.
- ✓ Characteristic curves of the dynamic components, *i.e.* turbine and compressors, are produced at a 3600 rotational speed.

The governing equations for the fluid mass, momentum, and energy are given as follows.

$$\sum_k \dot{m}_k = \dot{m} \quad (1)$$

$$\sum_k \cdot p_k = 0 \quad (2)$$

$$\sum_k \dot{Q}_k = 0 \quad (3)$$

Characteristic curves of a turbine are expressed as a function of three variables of the power or torque, mass flow rate, and pressure ratios. Characteristic curves of the compressors are expressed as function of two variables, pressure ratio or power against the mass flow rate. Dynamic information on the components can be obtained from a CFD analysis [2][3][4]. Geometries of each heat exchanger are given from the heat exchanger sizing computational code. Additionally, Hesselgreaves and Ishizuka correlations are used to solve a heat transfer coefficient and a pressure drop in each heat exchanger [5][6]. Characteristic curve of a control valve is assumed as the mass flow rate is changed linearly in a pressure range from 0.5 to 1.0. Fig. 2 and 3 show the results of the change of the control valve openings from which the amount of Na-CO2 heat exchange was determined. The flow chart of the analysis code developed in this study is described in Fig. 4.

3. Conclusions

The calculated code results correspond with a design condition at a full power within an error of 0.1%. At a reduced valve opening, the system efficiency increases between 60% and 80% of the Hx total heat transfer rate. This is because the HTR heat transfer rate is dominantly affected by the mass flow split ratio. Since the temperature of the HTR cold-side is higher than that of the HTR hot-side, the performance analysis code does not converge in a condition less than 50% of the Hx total heat transfer rate. Therefore it should be dealt with by a local system control method.

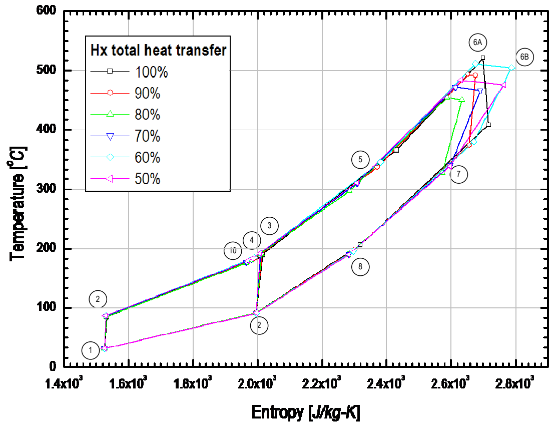

Fig. 2 T-S diagram according to valve opening

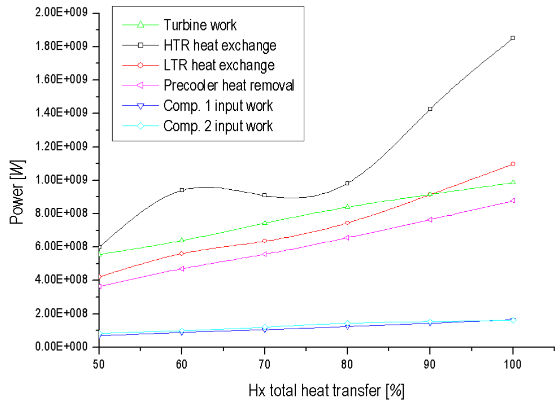

Fig. 3 Power of each component according to valve opening

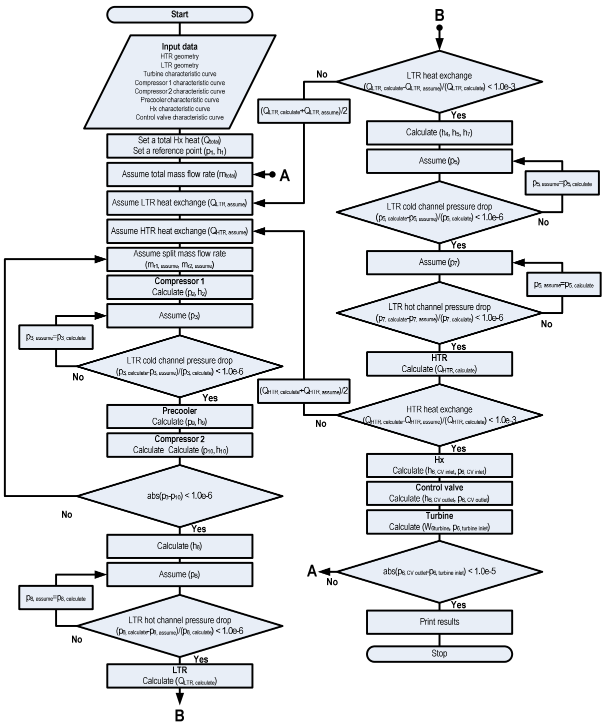

Fig. 4 Computation flowchart of the off-design analysis code

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