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A Study about Supercritical CO_2 Brayton Cycle Transient Control by using MARS Code

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1. Introduction

An I-NERI Project concerning the liquid metal reactor and related power conversion system has been launched in October 2005 [1]. The objective of this three year joint project between Argonne National Laboratory (ANL) and KAERI is to develop supercritical carbon dioxide (S-CO_2) Brayton cycle energy conversion systems and evaluate their performance when they are coupled to advanced nuclear reactor, i.e., GEN IV types. Among the several tasks of the I-NERI-joint project, the objective of the Task 4 is to identify the accidents involving the super-critical CO_2 Brayton cycle power and to assess the impact of those accidents upon the reactor system safety performance.

As the first step of the whole system transient analysis, the S-CO_2 Brayton cycle is analyzed after decoupled from the reactor system except the Na-CO_2 heat exchanger boundary. The Na- CO_2 heat exchanger provides the heat flux conditions for the analysis process.

MARS code [2-4] has been chosen as the Numerical method to analyze the transient of the S- CO_2 Brayton cycle.

2. Modeling of Brayton Cycle

The input text of MARS for the KALIMER-600 S-CO_2 Brayton cycle has the form of the modular components. The components are combination of the regular volume and junction, which are the basic elements of the continuity and momentum equations. The used modular components are single volume (SNGLVOL), time dependent volume (TMDPVOL), turbine (TURBINE), compressor (PUMP), pipe (PIPE), valve (VALVE), branch (BRANCH), single junction (SNGLJUN), time dependent junction (TMDPJUN), etc. In addition to these, shaft component is used to connect a turbine and 2 compressors. It is possible to make any configuration of power conversion system with the component-wise input structure. For each component, the simplified geometrical description and thermal states are required as the initial condition.

Only the CO_2 gas is used in current Brayton system, the mass and energy transfer between phases are ignored and the related terms are useless. But, there is a possibility of moisturizing of CO_2 gas when the pressure decreases below the critical point. The moisture may cause severe hazard on the blade of turbo machineries.

The S-CO_2 Brayton cycle modeling is shown in **Figure 1**. The Na- CO_2 heat exchanger is postulated as a heat flux source. The heat flux value is assigned as a boundary condition. Before the detail geometrical cycle inputs are not prepared yet, making closed loop steady run state requires the pressure boundary operation first. After the turbine component, i.e, the HTR(High Temperature Recuperator), LTR(Low Temperature recuperator), COOLER, COMP1, and COMP2 are all set to have the state as 9.5MPa and 713.15K. **Figure** 2 shows the pressure boundary operation schematics.

As in the figure, the time dependent volume 001 and 910 provides the pressure boundary, which is controllable by the user. Initially 19.74MPa, 781.15 K is assigned as the thermal conditions for the time dependent volume 001. The pressure and temperature condition of time dependent volume 910 are the set the same to those of 001. The Na-CO_2 heat exchanger flux value is initially set as 100 W/m2.

The turbine and compressors are set to rotate at 188.5 rad/s. The rotation velocity is maintained for the whole calculation. It is assumed that the generator produces 60Hz electricity with the dual phases.

From these initial condition settings, the pressure of outlet boundary and the heat flux value are moderately increased up to normal steady state values.

3. Transient Control for 80% power

After achieving the closed loop steady condition, transient runs are performed. The heat flux input at the Na-CO_2 heat exchanger boundary is adjusted from 29,850 W/m^2, the steady value to 23,880 W/m^2, the 80 % level of the steady value in 100 second.

After holding the 80% level for 900 seconds, the heat flux increases to 100% level again in 100 seconds. During the heat flux adjusting period, the COMP1 inlet pressure decreases and causes the COMP1 failure of under-critical states if there is no valve actions. To prevent the under-critical state of COMP1 inlet, the CO_2 supply inventory is open by the control logic. When the cooler outlet pressure reaches at 7.4MPa, the valve 640 is controlled to supply CO_2 gas. The supply inventory is kept as 8.4 MPa.

As the results, the pressures and the temperatures for other components are monitored and compared to the ‘no control’ case.

4. Conclusion

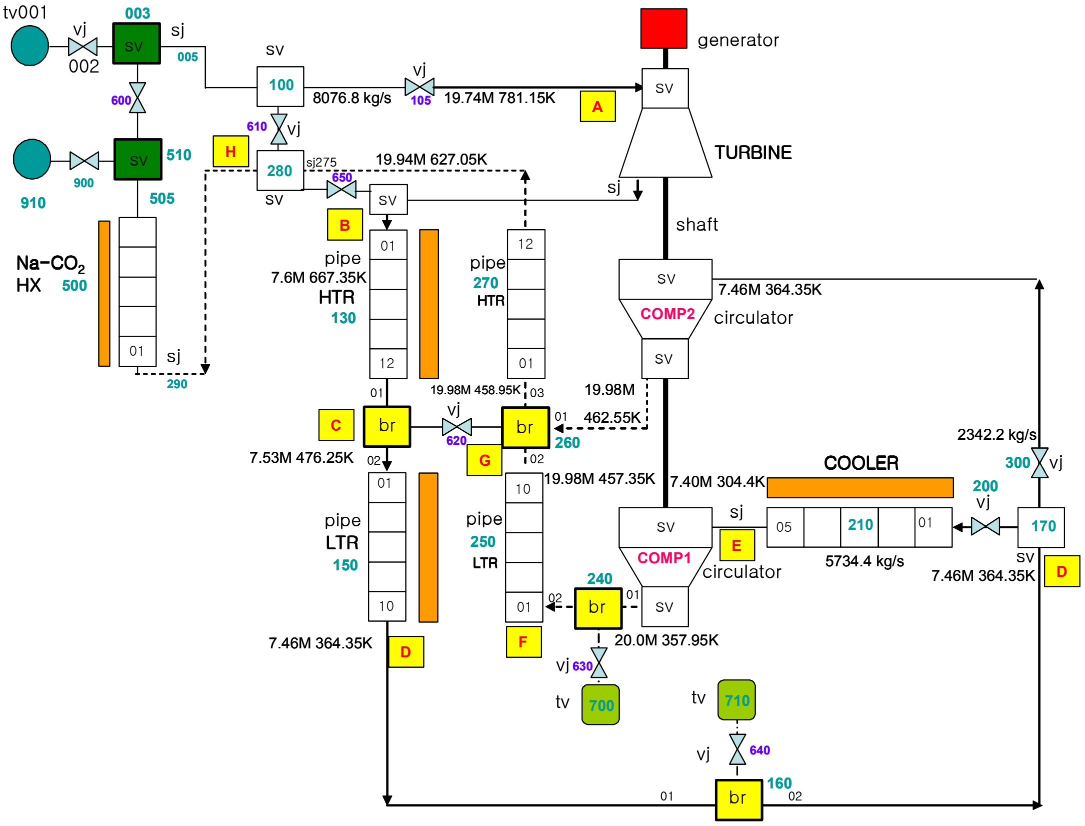

Figure 1. A Schematic Nodalization of S-CO2 Brayton Cycle

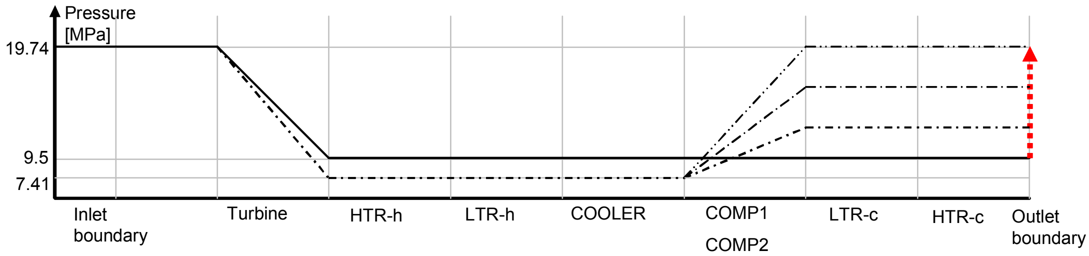

Figure 2. Diagram of pressure boundary adjusting sequences

The S-CO_2 Brayton cycle nodalization is made and used in MARS code. For the core power decreasing event, the transient inventory control processes are investigated. The supply of CO2 gas through the upstream of the cooler makes effective prevention method from the under-critical failure state of compressor.

Acknowledgement

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References

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