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Transient analysis and validation with experimental data of supercritical CO_2 integral experiment loop by using MARS

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ABSTRACT

To develop a cycle operation strategy for a supercritical carbon dioxide (S-CO_2) Brayton cycle, a series of MARS code simulation results were compared to experimental data from an SCIEL compressor test, which was collected at both component and whole-loop level. The simulation results show reasonable agreement with the experimental results. The MARS code was used to simulate behavioral responses at varying scenarios, the valve control for cycle operation, a power swing to simulate load following behavior, and an effect of the heat sink reduction to simulate failure. The electric power output of the turbine decreased to 50% of that during normal operation through valve control. After power swing, the system reverted to the initial steady-state conditions. The fluid behavior in precooler and the eventual change in the system were identified through the scenario of the heat sink reduction. The simulations provide a notable insight into the responsiveness of an SCIEL to these variable scenarios. Even though the MARS code was specifically developed for analysis of water reactor transients, its field of application may be extended to analyze the S-CO_2 Brayton cycle, and may thus assist with the development of control strategies for SCIEL and the S-CO_2 Brayton cycle.

1. Introduction

The supercritical carbon dioxide (S-CO_2) Brayton cycle is a promising power conversion system with benefits of high thermal efficiency, simple cycle layout, compactness of components, and wide operation range [1]. These advantages are the result of the high density and low compressibility of S-CO_2 near the critical point of CO_2 (30.98 °C, 7.38 MPa) due to wide and rapid variation in the thermodynamic properties of S-CO_2 near this point [1,2]. Because of these advantages, the S-CO_2 Brayton cycle has been evaluated as a power-conversion system for numerous applications, including nuclear, geo-thermal, solar, and thermal power plants. Use of the S-CO_2 Brayton cycle in Sodium-cooled Fast Reactors (SFRs) may eliminate the risks of sodium-water reactions [3]. The efficiency of the S-CO_2 Brayton cycle is competitive with the steam Rankine cycle, which is the conventional power conversion system. The S-CO_2 Brayton cycle is also considered as an alternative power generation system for small modular reactors (SMR), that have small, modularized components and capacities 50–300 MW_{th} [4]. An SMR with the S-CO_2 Brayton cycle can achieve high mobility and reduction of construction period and cost.

The properties behavior of CO_2 changes drastically and rapidly near its critical point. Therefore, the development of a feasible S-CO_2 Brayton cycle power-conversion system is dependent on an adequate technique that promotes a stable operational cycle near the critical point of S-CO_2, but experience with operation of the S-CO_2 Brayton cycle is insufficient, so the S-CO_2 Byraton cycle operation technique must be studied and refined to safely operate the system. Experiment and transient analysis of the S-CO_2 Brayton cycle should be performed to develop a new cycle control method and an ideal analysis platform to operate and control the S-CO_2 power generation system.

Various tool for transient analysis and analysis results are existed [5–16]. Among them, to meet these requirements, previous transient analyses of the S-CO_2 Brayton cycle were performed with various heat sources [9–16]. Transient analyses have been performed by using the IST plant TRACE model [12], using Plant Dynamics Code (PDC) [13], using RELAP5-3D about the S-CO_2 Brayton cycle coupled with nuclear fusion reactor [15], and using GAMMA code [16]. Some of the previous studies performed only code

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