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500 kW supercritical CO_2 power generation system for waste heat recovery: System design and compressor performance test results

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ABSTRACT

The supercritical CO_2 Brayton cycle has received attention as a next generation power conversion system. However, technical challenges that relate to the design and operation of the system remain to be overcome. In particular, achieving turbomachinery operation with design points is imperative to demonstrate the feasibility of the technology. This study aims to provide the current research status of the supercritical CO_2 power generation system in KAERI, with a focus on the detailed design of the system and operation of the compressor. In this study, cycle design (a simple recuperated cycle layout) of the system was developed using an in-house code for the optimization of a pilot plant of a 500 kW supercritical CO_2 power generation system for waste heat recovery. A thermal efficiency of 16.5% of the proposed cycle was achieved. In addition, the detailed design of key components, such as turbomachines and heat exchangers, was developed. Furthermore, the first-step configuration, a compressor performance test loop, of the supercritical CO_2 power generation system pilot plant was accomplished. The compressor was designed and manufactured as a hermetic system for the supercritical CO_2 power generation system. A compressor performance test was conducted to verify the target performance of the compressor. The operation of the compressor at the design point was achieved during the test; the compressor inlet was 33 °C at 7.68 MPa, and the compressor rotational speed was 34200 rpm; its efficiency was 83.7%, and the pressure ratio was 1.756.

1. Introduction

The power generation industry aims to achieve higher thermal efficiency in their processes to lower costs and reduce emissions, which will help protect the environment. Approximately 45% of the industry's energy is lost to the atmosphere via exhaust gases [1], which results in a significant waste of energy and considerable environmental pollution. The generation of additional power by recovering waste heat may result in economic benefits.

The organic Rankine cycle (ORC) has proven to be an effective method for waste heat recovery. Many previous studies have concentrated on finding the ORC working fluid [2,3] and cycle layout [4,5]. However, the high temperature of the exhaust gas from the turbine may lead to the decomposition of the fluid of the ORC, which restricts the application of the ORC in waste heat recovery [6,7]. Moreover, the ORC system has a large size compared with the gas turbine. Therefore, a highly efficient, simple, compact, and relatively low-cost power conversion system to recover the waste heat from gas turbines is a necessary.

Various power conversion systems have been suggested and been the subject of research for waste heat recovery. Among these systems, the supercritical CO_2 (sCO_2) Brayton cycle (BC) was considered one of the most promising innovative power conversion systems for waste heat recovery. sCO_2 is a promising fluid for next-generation power conversion systems for various heat sources: coal-fired, nuclear reactors, concentrating solar power (CSP), fuel cells, and waste heat recovery [8]. Conventional BC has a low cycle efficiency owing to its high compression work. However, the sCO_2 BC can attain a high thermal efficiency based on the thermo-hydraulic characteristics of CO_2 near the critical point. sCO_2 has a high density and low compressibility factor. Therefore, the sCO_2 BC significantly reduces the compressor work compared with the conventional BC such a helium, nitrogen and air BC. In addition, the sCO_2 BC has the advantages of simple cycle layout, compactness of

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