



Optimization and thermodynamic analysis of supercritical CO₂ Brayton recompression cycle for various small modular reactors



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ABSTRACT

This paper presents optimization of a supercritical carbon dioxide Brayton cycle for three types of 300-MWth small modular reactors (SMRs); a pressurized water reactor (PWR), a sodium-cooled fast reactor (SFR) and a high-temperature gas-cooled reactor (HTGR). The parameters of the pressure ratio and the flow split fraction were examined for sensitivity analysis and optimization of cycle. The optimized cycle efficiencies of PWR, SFR, and HTGR were 30.6%, 46.38%, and 50.04%, respectively. Key components, i.e. turbomachinery and heat exchangers for the SMRs were designed to develop the optimized cycles. The cycle thermal efficiency was improved by using investigating the effects of the channel shape (zigzag, s-shape, airfoil fin) of the printed circuit heat exchangers (PCHEs) on the pressure drop. The study indicated that using airfoil fin type PCHE may increase the cycle thermal efficiency by about 1.0% in comparison with zigzag type PCHE. The effect of turbomachinery efficiencies on the cycle thermal efficiency were investigated.

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1. Introduction

The supercritical carbon dioxide (S-CO₂) Brayton cycle has high thermal efficiency, simple cycle layout, compactness of component and wide operation range [1]. These advantages are the results of the high density and low compressibility of CO₂ near its critical point (304.13 K, 7.38 MPa) due to wide and rapid variation in the thermodynamic properties [1]. Because of these advantages, the S-CO₂ Brayton cycle has been evaluated as a power conversion system for numerous applications, including nuclear, geo-thermal, solar, and thermal power plants. Also, based on advantages, the S-CO₂ Brayton cycle can achieve higher thermal efficiency and smaller cycle layout than the conventional steam Rankine cycle. Therefore, S-CO₂ Brayton cycle can be a good alternative to steam Rankine cycle.

Research effort to find alternative methods of generating electricity has been discussed during the 60's. In 1967, simple regenerative cycle layout was proposed by Feher, during find the application of the supercritical fluid cycle [2]. Several cycle layouts can be proposed and one of the most detailed investigation on that

topic have been conducted by Angelino in 1968 [3]. Angelino thus stated that the recompression cycle is suitable for high temperature nuclear heat sources [3]. Also, Dostal et al. evaluated the S-CO₂ Brayton cycle for advanced nuclear reactors for power generation application using the basic thermodynamic approach [1].

Recently, the S-CO₂ Brayton cycle is being studied for various applications; such as nuclear power plants, solar concentration plants, waste heat recovery systems, coal-fired plants and so on. Many studies have been conducted to apply the S-CO₂ Brayton cycle to nuclear reactors, such as Sodium cooled Fast Reactors (SFRs), fusion reactors, and Small Modular Reactors (SMRs). A comparison between steam, helium and CO₂ cycles for prototype fusion power reactors has been conducted, and the S-CO₂ Brayton cycle is recommended because of its efficiency and small size [4]. Also, energetic and exergetic analyses have been conducted for a recompression S-CO₂ Brayton cycle to optimize the effect of various operating and design parameters on the cycle's efficiency in nuclear applications [5]. The S-CO₂ Brayton cycle for SMRs with recompression cycle have been studied [6]. Previous research concluded that S-CO₂ Brayton cycles are a viable alternative option [7]. The S-CO₂ Brayton cycle has become one of the most promising thermodynamic cycle for SFRs [8]. Cycle optimization of the S-CO₂ system was conducted for SFRs [9,10]. The study of the off-design behaviour of the S-CO₂ recompression cycle in increasing heat

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