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# Evaluation of supercritical CO<sub>2</sub> compressor off-design performance prediction methods



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#### ABSTRACT

A supercritical CO<sub>2</sub> (S–CO<sub>2</sub>) Brayton cycle has a compact and simple layout, which suggests the possibility to serve as a small scale distributed power conversion system. Off-design behaviors of each component determine the system off-design performance in the S–CO<sub>2</sub> power cycle. Among components, compressor performances have the largest impact on the system off-design analysis since it operates nearest to the critical point of CO<sub>2</sub>. In the system analysis, the off-design performance of a compressor is usually pre-calculated for the fixed inlet conditions. The performance map is then converted for the off-design performances prediction using corrected mass flow rate and corrected rpm. Similitude models are used for the conversion. Several similitude models have been developed mostly for air conditions previously, but the applicability of these models to S–CO<sub>2</sub> still needs to be tested. In this paper, to evaluate the existing models for the S–CO<sub>2</sub> conditions, experimentally validated 1D mean-line code is used to generate wide range of S–CO<sub>2</sub> compressor data set. As a result of the evaluation, Pham model showed the most accurate enthalpy rise prediction resulting in the best pressure rise prediction, and the efficiency prediction could be modified with density correction to improve the off-design performance prediction.

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### 1. Introduction

Most of the power plants mainly have adopted a steam Rankine cycle or a gas Brayton cycle until now. Since the invention of energy conversion through a thermodynamic cycle, there has been always a great emphasis on energy source and power cycle to convert energy into useful work i.e. electricity. At the same time, to devise a better power conversion cycle, various approaches were taken by researchers. One of the examples is an S-CO<sub>2</sub> (supercritical CO<sub>2</sub>) Brayton cycle. Basically, an S-CO<sub>2</sub> Brayton cycle is a variation of Brayton cycle. In contrast to the fact that an ordinary Brayton cycle operates with a gas phase fluid, S-CO<sub>2</sub> power cycle operates with a supercritical fluid, where temperature and pressure of working fluid are above the critical point. Many advantages of S-CO<sub>2</sub> power cycle are rooted from its novel characteristics. The fluid has liquid like high density, but at the same time, gas like low viscosity. Furthermore, the fluid properties near the critical point show dramatic changes and highly non-linear behaviors, significantly

\* Corresponding author. E-mail address: jeongiklee@kaist.ac.kr (J.I. Lee). deviating from ideal gas [1]. One particularly important thermodynamic property is the compressibility and it is reduced greatly near the critical point. Due to these benefits,  $S-CO_2$  power cycle can be utilized with simple and compact layout to produce electricity efficiently.

Over the past decades, the S-CO<sub>2</sub> power cycle was invented and studied. Eventually the cycle was revisited by Dostal [2] and succeeded in attracting significant attention around the world. It was confirmed that the advantages of an S-CO<sub>2</sub> cycle were not just confined to a specific application, but also can be widely applicable to other areas such as advanced fossil fuel [3,4], concentrated solar power [5–7], waste heat recovery [8,9], and nuclear power [10,11]. Especially, its compactness and simple layout will lead to the possibility to serve as a small or medium scale power conversion system for a distributed power source. Most of the large scale power plant usually operates at the design point where the system shows its best performance. However, a small scale system for a distributed power source is more likely to operate under off-design conditions as a response to the load variation and external environmental conditions change. Thus, to analyze the off-design behavior of the S-CO<sub>2</sub> power cycle, many research works are in

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