Energy 213 (2020) 119071

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Evaluation of supercritical CO_2 compressor off-design performance prediction methods

Yongju Jeong [a], Seongmin Son [a], Seong Kuk Cho [a], Seungjoon Baik [b], Jeong Ik Lee [a, *]

[a] Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, South Korea
[b] Korea Atomic Energy Research Institute, South Korea

ARTICLE INFO

Article history:
Received 21 January 2020
Received in revised form
13 June 2020
Accepted 11 October 2020
Available online 15 October 2020

Keywords:
Supercritical CO_2
S–CO_2 compressor
Off-design performance prediction
Similitude analysis
Performance map

ABSTRACT

A supercritical CO_2 (S–CO_2) 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_2 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_2. 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_2 still needs to be tested. In this paper, to evaluate the existing models for the S–CO_2 conditions, experimentally validated 1D mean-line code is used to generate wide range of S–CO_2 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.

© 2020 Elsevier Ltd. All rights reserved.

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_2 (supercritical CO_2) Brayton cycle. Basically, an S–CO_2 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_2 power cycle operates with a supercritical fluid, where temperature and pressure of working fluid are above the critical point. Many advantages of S–CO_2 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 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_2 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_2 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_2 power cycle, many research works are in

* Corresponding author.
E-mail address: jeongiklee@kaist.ac.kr (J.I. Lee).

https://doi.org/10.1016/j.energy.2020.119071
0360-5442/© 2020 Elsevier Ltd. All rights reserved.