Applied Energy 206 (2017) 1118–1130

Contents lists available at ScienceDirect

Applied Energy

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

Thermodynamic study of supercritical CO_2 Brayton cycle using an isothermal compressor

Jin Young Heo, Min Seok Kim, Seungjoon Baik, Seong Jun Bae, Jeong Ik Lee*

Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea

HIGHLIGHTS

- The performance of isothermal compressor for s-CO_2 power cycles is assessed.
- Using the isothermal compressor in three s-CO_2 cycle layouts improves performance.
- Results of cycle optimization using isothermal compressors are included.
- Partial heating cycle, used in waste heat recovery, is assessed and modified.

ARTICLE INFO

Keywords:
Isothermal compressor
Supercritical carbon dioxide (s-CO_2) cycle
Thermodynamic study
Waste heat recovery

ABSTRACT

In this paper, a thermodynamic study of newly suggested supercritical carbon dioxide (s-CO_2) cycle layouts using an isothermal compressor is presented. The isothermal compressor is conceptually defined using the 'infinitesimal approach' in attempt to resolve the ambiguity in its performance framework. As part of preliminary investigation, the isothermal compressor is demonstrated thermodynamically, and the calculations highlight that it reduces the compression work significantly under s-CO_2 power cycle operating conditions over other representative working fluids. The in-house code is modified to allow the analysis of three s-CO_2 cycle layouts, simple recuperated Brayton cycle, recompression Brayton cycle, and partial heating Brayton cycle, adopting the isothermal compressor. The cycle performance is evaluated through a sensitivity analysis of cycle design parameters, pressure ratio and flow split ratio. When the machinery is applied, the cycle net efficiency of the simple recuperated cycle and the recompression cycle is improved by 0.5% point and 1–3% points, respectively. Moreover, the partial heating cycle layout, known for its outstanding performance in waste heat recovery applications as a bottoming cycle, produces 15–18% more net work when using an isothermal compressor, compared to the reference cycle. Overall, the use of the isothermal compressor not only improves the general cycle performance, but also provides another degree of freedom for cycle design optimization of s-CO_2 cycles.

1. Introduction

To address global warming issues, many energy technologies are being developed to improve energy efficiency in existing systems. It is logically desirable to install a more efficient conversion system in place of existing ones to make best use of the given energy source. To improve the current power cycles including the steam Rankine cycle, new energy conversion systems for various energy applications have been suggested and developed. These include organic Rankine cycle (ORC) for lower temperature applications [1], along with helium and nitrogen Brayton cycles [2] for medium to high temperature applications. Amongst several cycles based on alternative working fluids which prove advantageous for specified purposes, the supercritical CO_2 (s-CO_2) Brayton cycle technology has been receiving attention due to its potential for use in several energyapplications including fuel cells, concentrated solar power, gas turbine, geothermal, coal power, and nuclear energy [3–7].

One of the key advantages of the s-CO_2 Brayton cycle technology includes compact turbomachinery due to the high density of the working fluid. Because of the high density of s-CO_2 near the critical point, the turbomachinery sizing can be reduced effectively in comparison to the steam Rankine cycle hardware. From Ahn et al. [7], the s-CO_2 turbomachinery becomes 10 times smaller than that of the steam Rankine cycle. Furthermore, the overall system size can be reduced up

* Corresponding author.
E-mail addresses: jyh9090@gmail.com (J.Y. Heo), minskim@kaist.ac.kr (M.S. Kim), bsj227@kaist.ac.kr (S. Baik), seongjunbae@kaist.ac.kr (S.J. Bae), jeongiklee@kaist.ac.kr (J.I. Lee).

http://dx.doi.org/10.1016/j.apenergy.2017.08.081
Received 21 February 2017; Received in revised form 3 May 2017; Accepted 11 August 2017
Available online 04 October 2017
0306-2619/