Applied Thermal Engineering 229 (2023) 120560

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

# A two-stage sodium converter coupled to a two-stage TEG: Parametric optimization

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ARTICLE INFO

*Keywords:*
Two-stage sodium thermal electrochemical converter
Two-stage thermoelectric generator
Parametric selection criterion
Coupled system
Pareto front
Irreversible loss

ABSTRACT

The aim of this study is to deeply study and analysis of energetic performance of the novel coupled system composed of a two-stage sodium thermal electrochemical converter and a two-stage thermoelectric generator. The main methods are to establish the model of the coupling system by considering the main irreversibilities, and obtain the analytical expressions of the power outputs and efficiencies of two subsystems and coupling system. The main novelties are to obtain the optimum ranges of critical parameters of the coupled system and give the reasonably matching conditions between the subsystems. The main contents of this study include that the influences of the intermediate and condenser temperatures of the sodium thermal electrochemical converter and current density of the first stage sodium thermal electrochemical converter as well as the electric current of the two-stage thermoelectric generator on the efficiency and power output density are discussed and the maximum power output density and efficiency of the system are calculated and compared with those of the single two-stage sodium thermal electrochemical converter and the existing coupling models. Results show that the maximum efficiency and maximum power output density of the coupled system attain 0.413 and $68.7 \times 10^3$ W m$^{-2}$ and exhibit an improvement of about 14.1% and 66.7% than those of the standalone two-stage sodium thermal electrochemical converter respectively, and the maximum efficiency of the whole system increase 37.7% compared with that of the existing coupling system. The results obtained indicate that the performance of the proposed system is greatly improved by efficient the exhaust heat utilization. In addition, the multi-objective and multi-parametric optimization analyses are adopted to search for the global optimization profile and validate the obtained findings.

## 1. Introduction

A sodium thermal electrochemical converter (Na-TEC) is a unique electrochemical device that converters heat into electricity directly, using usually the sodium as the working fluid [1]. The Na-TEC shows the attractive advantages of high efficiency (0.2–0.4), solid-state operation, noise-free, low maintenance requirements, high reliability, and various heat sources including nuclear, fuel combustion, and concentrated solar so that it is well suited for a broad number of applications including space, aerospace, military, and domestic fields [2].

The evaporator and condenser temperatures of Na-TEC are in the region of 900–1300 K and 400–800 K higher than the environment temperature, respectively, where heat directly released from condenser will provoke environmental thermal damage and energy wastage. Therefore, great efforts have been devoted to the research and development of the Na-TEC by theoretical and experimental improvements [3,4]. On the one hand, some researchers were attracted to improving the power output (PO) and efficiency of the Na-TEC device [5–11]. Lodhi et al. [5], by changing some geometrical dimensions of the cell, improved the efficiency of the Na-TEC cell by up to 17.5% over that in operation called Ground Demonstration Converter System at Air Force Research Laboratory, Albuquerque, New Mexico. Lodhi et al. further improved the PO and efficiency by optimizing the thickness of

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https://doi.org/10.1016/j.applthermaleng.2023.120560
Received 15 November 2022; Received in revised form 30 March 2023; Accepted 7 April 2023
Available online 11 April 2023
1359-4311/