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A two-stage sodium thermal electrochemical converter: Parametric optimization and performance enhancement

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HIGHLIGHTS

- A two-stage sodium thermal electrochemical converter is updated.
- Main irreversible losses are considered and the coupling of two stages is optimized.
- The maximum efficiency and power output density increase 17.5% and 40.6%.
- The optimum selection criteria of main parameters are supplied.
- The optimum energetic space is given by the Pareto front.

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ABSTRACT

An asymmetric two-stage sodium thermal electrochemical converter and its optimum performance are studied by means of an improved analytical model including the main losses in the overall system. Based on the study of a single-stage sodium thermal electrochemical converter, the inner process is divided into two stages including one at the 1300 K temperature (evaporator) and the other at the 800–1300 K intermediate temperature with the aim of improving efficiency. The parametric optimum selection criteria of a few main parameters of the two-stage device are provided and the coupling of the separate stages in an overall optimum system in terms of the appropriate intermediate temperature is particularly stressed. The maximum efficiency of the proposed overall system can attain 36.2%, which is 17.5% higher than that of the best performing single-stage device, and increase up to 34.1% and 24.8% over the existing two-stage devices designed by two research groups, respectively. The Pareto front obtained from numerical multiobjective and multiparametric methods endorses previous findings and visually presents the space of the states and the energetic properties of the overall arrangement compared with the corresponding data for the isolated first and second stages.

1. Introduction

A sodium thermal electrochemical converter (Na-TEC), which is one promising thermally regenerative electrochemical system, converts directly heat into electricity by the isothermal expansion of sodium ions through a β''-alumina solid-electrolyte (BASE) allowing for Na^+ ion transport in a wide temperature range [1,2]. The emerging Na-TEC [also named as the alkali metal thermal electric converter (AMTEC)] can be traced back to the 1960s, and the technology, primarily for the NASA Pluto/Express spacecraft mission [3], attracted extensive attention in the 1990–2000s for space applications. Some seminal studies on Na-TEC systems have been reported. For example, Weber [4] presented a theoretical analysis and described the construction of a model beta-alumina thermoelectric generator. Cole [2] studied the thermodynamic operating principles and gave some crucial expressions including current-voltage relation and efficiency. Williams et al. investigated the kinetics and transport at electrodes including the interfacial impedance model [5] and the dependence of the interfacial impedance of Na (g)/porous Mo/Na-Beta-double prime alumina on temperature [6]. It is

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