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A novel electrochemical system with adiabatic pre-charging and pre-discharging processes for efficient refrigeration

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A B S T R A C T

The extraordinary thermal-to-electricity conversion efficiency of thermally regenerative electrochemical cycle triggers interest in its reverse counterpart, namely thermally regenerative electrochemical refrigerator (TRER), a promising alternative to conventional cooling devices. Nevertheless, due to three fundamental obstacles, the practically feasible TRER model is still absent, which hinders the development of follow-up research. To break this bottleneck, heating by discharging and cooling by charging effects are innovatively utilized to construct TRER models where the electrochemical counterparts of traditional adiabatic compression and expansion processes, namely adiabatic pre-charging and pre-discharging processes, are proposed and introduced. Significantly, the maximum coefficient of performance (COP) and the COP at maximum cooling power are predicted to achieve up to 40% and 5% of Carnot COP, respectively for the given values of parameters. Moreover, the great potential for efficient refrigeration is highlighted by comparing the obtained results with various refrigeration systems. This work lays the foundation for further experimental investigations and opens a new avenue for constructing other novel electrochemical cycles.

1. Introduction

The widely used vapor-compression refrigeration systems consume approximately 10% of the electricity generated worldwide [1] and represent a significant fraction of the gas emission contributing to ozone depletion and global warming [2], which fuels the global energy crisis and environmental problems. Regarding this concern, various novel refrigeration technologies, such as adsorption refrigeration [3], thermoelectric cooling [4,5], magnetic refrigeration [6], barocaloric refrigeration [7], thermal Brownian refrigeration [8], thermionic refrigeration [9], and energy selective electron cooling [10] have been continually proposed and extensively studied. Although the fundamental understanding and practical improvement have been remarkable, these alternatives are still facing the challenges in efficiency, cost, and system complexity to compete with conventional refrigerators. Consequently, it is of great significance to further explore better refrigeration technologies.

Recently, based on the thermogalvanic effect and the temperature dependence of electrode potential, a novel thermally regenerative electrochemical cycle (TREC) employing highly reversible electrode materials with low polarization has been put forward for efficiently harvesting low-grade thermal energy [11]. Notably, a high thermal-to-electricity conversion efficiency of 5.7%, corresponding to approximately 38% of Carnot efficiency, is achieved when the system is operated between 10 and 60 °C [11]. The extraordinary conversion efficiency in both high and low temperature applications, along with the merits of reliability, quietness, and environmental friendliness, has triggered the heated researches about TERC once again. Considerable efforts have been dedicated to exploring materials with larger temperature coefficient [12–15] and lower resistance [16]. To minimize costs, simplify the system, and achieve continuous power output, membrane-free [17], charging-free [18,19], and continuous [19–24] TREC systems have been proposed, respectively. Besides, several objective functions [24,25] have been adopted to provide more comprehensive operation criteria. In addition, various electrochemical cycle configurations, such as electrochemical Carnot cycle [26] and electrochemical Brayton cycle [27], have been presented, analyzed, and compared. Moreover, with the

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