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OPTIMAL PERFORMANCE OF THERMOELECTRIC DEVICES WITH SMALL EXTERNAL IRREVERSIBILITY

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ABSTRACT

In thermodynamic analysis of thermoelectric devices, understanding and mitigating irreversibilities is key to optimizing performance. Two primary irreversibilities affect device performance: internal (e.g., Joule heating and heat leakage) and external (due to heat transfer through heat exchangers) [1,2]. Traditional analyses focus on these separately, leading to efficiency expressions, such as those derived by Curzon-Ahlborn and Schmiedl-Seifert for endoreversible and exoreversible models, respectively. However, real-world devices experience both types, with internal irreversibilities linked to the material's figure of merit and external ones arising from heat exchanger conductance. We address this by formulating a scenario within the Constant Properties model [3,4] that accounts for both simultaneously.

Our study introduces the symmetric and small external irreversibility (SEI) model [5], where external irreversibilities are confined to the regime of large external conductance relative to the internal thermal conductance of the thermoelectric material. By incorporating this approximation, we derive a generalized expression for the efficiency at maximum power (EMP) that depends not only on the thermoelectric figure of merit and the temperature ratio but also on the ratio of internal to external conductance. This approach bridges the gap between simple idealized models and more realistic scenarios, enabling a more comprehensive understanding of thermoelectric device performance.

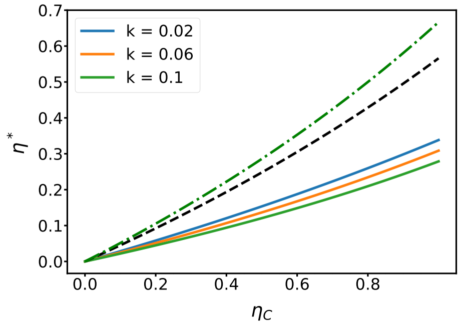

Figure 1: Efficiency at maximum power (EMP) vs. Carnot efficiency, η_C.

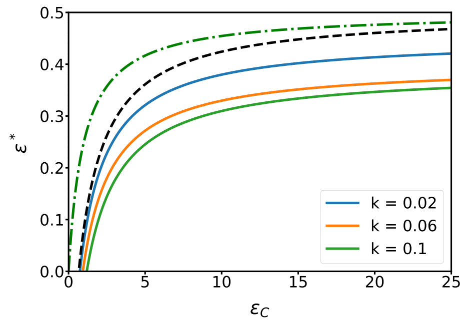

Figure 2: Efficiency at maximum cooling power vs. coefficient of performance of a Carnot refrigerator, ε_C.

We also extend our analysis to thermoelectric refrigerators, exploring efficiency at maximum cooling power. While previous studies suggest optimization is only feasible for the exoreversible model [6], our analysis shows that even with small external irreversibilities, valuable insights into cooling power performance can be gained.

This study highlights the SEI model as a key benchmark for thermoelectric devices where heat exchanger conductance exceeds that of the material. By integrating internal and external irreversibilities, it offers insight into the interplay between external and internal irreversibilities, which may guide their practical design.

Keywords: Thermoelectric devices, Irreversibilities, Efficiency at maximum power (EMP), Thermoelectric materials, Thermoelectric refrigerators.

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