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Cost–Performance Analysis and Optimization of Fuel-Burning Thermoelectric Power Generators

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Energy cost analysis and optimization of thermoelectric (TE) power generators burning fossil fuel show a lower initial cost compared with commercialized micro gas turbines but higher operating cost per energy due to moderate efficiency. The quantitative benefit of the thermoelectric system on a price-per-energy ($/J) basis lies in its scalability, especially at a smaller scale (< 10 kW), where mechanical thermodynamic systems are inefficient. This study is based on propane as a chemical energy source for combustion. The produced heat generates electric power. Unlike waste heat recovery systems, the maximum power output from the TE generator is not necessarily equal to the economic optimum (lowest $/kWh). The lowest cost is achieved when the TE module is optimized between the maximum power output and the maximum efficiency, dependent on the fuel price and operation time duration. The initial investment ($/W) for TE systems is much lower than for micro gas turbines when considering a low fractional area for the TE elements, e.g., 5% to 10% inside the module. Although the initial cost of the TE system is much less, the micro gas turbine has a lower energy price for longer-term operation due to its higher efficiency. For very long-term operation, operating cost dominates, thus efficiency and material ZT become the key cost factors.

Key words: Topping cycle, thermoelectric, energy production, energy cost

INTRODUCTION

A quarter of the world's population does not have access to sources of electric power.[1] Those people could take advantage of localized power generators by burning fuel for electricity. Even in power-rich countries, power shortages in the grid can impact modern lifestyles and have a significant negative social impact.[2] A significant increase of renewable sources must be considered for long-term social and human life sustainability in either of these situations. We have also studied the effective use of concentrated solar[3] and other renewable alternatives.[4] However, facing the above challenges, many populations need distributed power generation, even based on fossil fuels. For this purpose, we studied whether and how thermoelectric generators could work in this application when optimally designed. In previous work, we analyzed and optimized generic thermoelectric (TE) power generator systems for waste heat. We theoretically derived the cost impact of the element's geometry and the parasitic losses[5] to find the optimal trade-offs for cost effectiveness.[6] These effects were taken into account for "waste" heat ranging up to temperatures of 600°C.[7] Based on the same principle but also considering the cost of the heat source, we present herein an energy cost analysis for a TE power generator burning fossil fuel in comparison with micro gas turbines.[8]

The analysis considers the price per energy ($/J) for fuel as the operating cost and also considers the required initial investment. The currency in this article uses US $ and US ¢. The efficiency takes into account the useful energy output from the injected chemical energy from propane. A heat source temperature of 1980°C is used as the flame temperature.[9,10] Unlike waste heat recovery systems, the maximum power output from the TE

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