Applied Energy 215 (2018) 300–308

Contents lists available at ScienceDirect

Applied Energy

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

Portable thermoelectric power generation based on catalytic combustor for low power electronic equipment

C. Fanciulli[a,*], H. Abedi[a], L. Merotto[b], R. Dondè[b], S. De Iuliis[b], F. Passaretti[a]

[a] CNR – Institute of Condensed Matter Chemistry and Technologies for Energy, Via Previati 1/E, 23900 Lecco, Italy
[b] CNR – Institute of Condensed Matter Chemistry and Technologies for Energy, Via Cozzi 53, 20125 Milano, Italy

HIGHLIGHTS

- New TEG based on catalytic combustor is developed with a volume close to AA battery.
- The system is designed to be safe, accessible for portable use as electronic supplier.
- Our solution shows an alternative for low power supply open to further improvements.
- Characterization procedure is defined allowing deep understanding of the processes.

ARTICLE INFO

Keywords:
Thermoelectric generator
Catalytic combustor
Thermoelectric
Device

ABSTRACT

In recent years, the portable technology is receiving a great interest and significant improvement due to the progresses in electronic technology development and energy storage solutions. The decrease in power requirements for working energy systems, due to the increased efficiency and to the reduction in components size, opens the access to new solutions for power supplying. In particular, alternative backup systems for battery charging or replacement could be designed taking advantage of unconventional technologies. It is the case of small photovoltaic portable panels or fuel cells technology: in these solutions different sources are used to produce limited electrical powers required to keep devices on. In this paper, a thermoelectric solution for the power generation has been considered: the generator has been designed and assembled starting from a catalytic combustor. Catalytic combustion allows safe control of the processes, and the choice of a hydrocarbon fuel ensures the power availability and a fast recharge. The size of the system is set to fit a volume close to the one of AA batteries. The electrical power output obtained is close to 1 W with a cold side temperature below 40 °C. The limited values of these physical parameters allow obtaining a portable and safe device. The generator has been fully characterized in different ranges of fuel flow rates and the performances have been thoroughly analysed for processes optimization and efficiency improvement.

1. Introduction

Thermoelectric (TE) technology allows the direct conversion of heat into electrical power. The complete absence of moving mechanical parts makes this technology highly reliable for long term waste heat recovery. The technology takes advantage of intrinsic material properties, therefore the operating behavior of a thermoelectric device is strictly and intrinsically related to the material used. Of course, some boundary conditions have to be considered, such as the maximum temperatures, the maximum heat flows and other parameters involved in the conversion process. The dimensionless figure of merit, ZT, associated to a thermoelectric material, describes the effective capability of the material to convert a heat flow into electrical power [1]. ZT parameter is also related to the maximum efficiency that a thermoelectric element can achieve operating at a certain ΔT. In Fig. 1 the efficiency of a thermoelectric device working between hot (T_h) and cold (T_c) temperatures, ΔT, is plotted for several ZT values. Increasing ZT values, the equation approaches the Carnot limit. At the same time the ZT slope decreases with increasing temperature gradient. In the inset the same data are reported in the range actually interested by available thermoelectric technologies.

As for the state of art of thermoelectric modules, chalcogenides based on Bi, Sb, Te and Se compounds are the only materials currently used for the fabrication of commercial modules. The materials

---

[*] Corresponding author.
E-mail address: carlo.fanciulli@cnr.it (C. Fanciulli).

https://doi.org/10.1016/j.apenergy.2018.02.012
Received 6 July 2017; Received in revised form 2 February 2018; Accepted 3 February 2018
0306-2619/

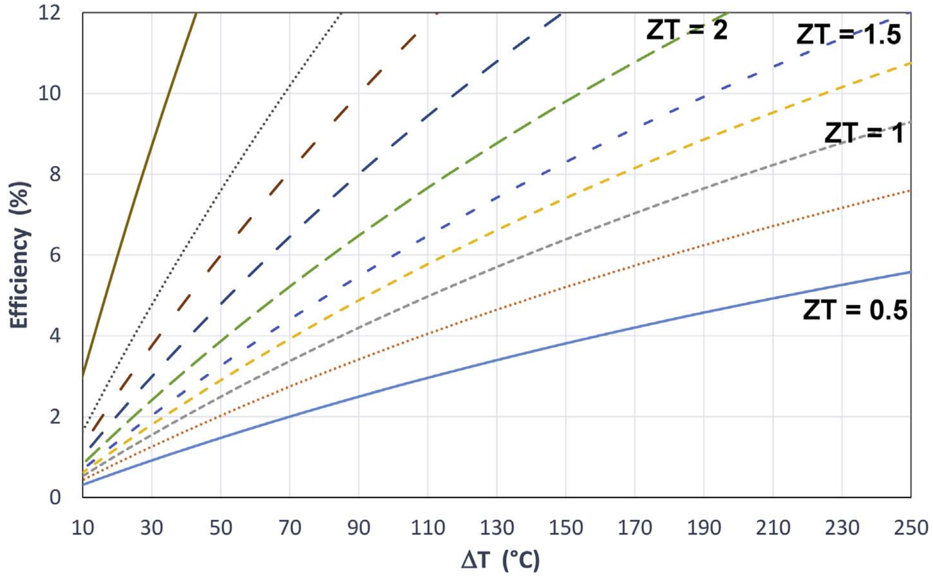

Fig. 1. Thermoelectric conversion efficiency vs. ΔT for different ZT values. The solid line corresponds to the Carnot limit efficiency. ZT values greater than 1.5 are reported to suggest the potential perspectives of the technology, even if they are, up to now, inaccessible.

characteristics in terms of chemical stability, mechanical properties and thermoelectric behavior, coupled with the technological solutions required for the module assembly, impose the operating boundary conditions for the devices. Usually, the best performances are obtained for ΔT between 200 °C and 250 °C, with an upper limit for T_h close to 300 °C. Higher working temperatures affect the reliability of the device, leading to materials aging or device performances degradation and failure. The ZT average value for this class of materials is close to 1 [2,3], therefore the theoretical efficiency achievable with actual commercial system is below 12%.

Recently, thanks to a growing interest in energy recovery solutions, several materials have been developed and studied [2–6] with the aim to achieve higher ZT values, for improvement in conversion efficiency, and higher working temperatures range. This second target, even not involving a significant change in the efficiency of the system, is important to open new fields of application for the thermoelectric technology.

In recent years optimized thermoelectric generators (TEG) for large scale applications based on low power requirements have been deeply investigated. It is important to underline the high reliability of these systems and their compactness and noiseless operating conditions, as well as their capability of taking advantage of any kind of heat, despite the low temperature. These aspects already made the TE solution successful for applications such as low temperature waste heat recovery or power generation in deep space exploration [7–9]. In Fig. 2 the comparison between the efficiencies of a TEG system and a standard engine is reported vs. the power output required [10]. It can be seen that below few hundreds of Watts, the thermoelectric system is advantageous thanks to its constant behavior.

Despite of the practical absence of thermoelectric generators on the market, an increasing number of studies have been performed for the evaluation of a thermoelectric solution in different cases of waste heat recovery or system efficiency improvement [11–27]. Here the attention moves on the capability of transferring the results produced on materials to the modules: the presence of electrical and thermal contacts necessary to embed the active elements, strongly affects the efficiency of the thermoelectric conversion. Looking at the results reported in literature and at the data for the commercial modules available, efficiencies between 1% and 5% are reported for the modules. Going down with the chain, the losses related to the thermal chain needed to transfer the heat from the hot source and to the cold sink have to be taken into account. In fact, each interface and thermal joint are responsible for losses in the heat transfer affecting the total efficiency of the thermoelectric generator (TEG). This reduction in efficiency represents the main limitation for TE technology. In all the applications based on TE modules, a significant drawback is due to the heat loss in the TE modules coupling [11,28]. Many interesting studies are oriented to the coupling of the thermoelectric technology to other systems, looking for an enhancement of the energy production performance of the overall system.

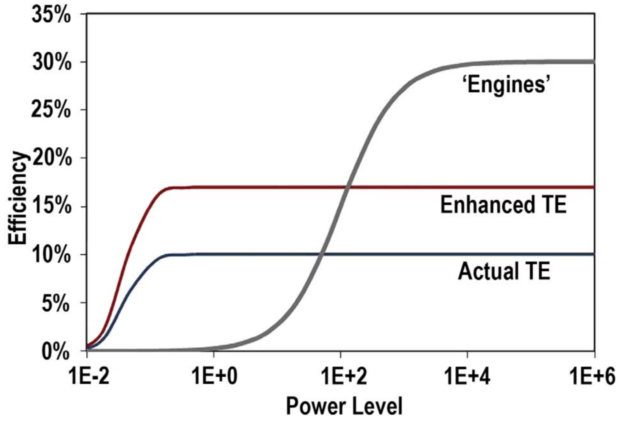

Fig. 2. Thermoelectric and 'engines' efficiency crossover vs. Power Outputs. Two curves for TE devices corresponding to different ZT values are reported [10].

The application of TE devices in micro power generation has gained also interest, given the need for power requirement reduction to fit the battery outputs. This interest has been also triggered by the development of miniaturization of mechanical and electromechanical engineering devices, especially in the areas of microelectronics, biomechanics, microfabrication techniques [29]. The aim is the development of power-supply devices with high specific energy (small size, low weight, long duration) [30,31]. The choice of the heat source is strictly related to the achievement of different efficiency limits. Due to the high energy content, hydrocarbon fuels can provide, even at low conversion efficiency, energy density higher than the most advanced batteries [32–35]. Therefore, hydrocarbon-based devices as portable power sources [34–39] could be considered a suitable solution as a heat source. In this context, catalytic reactors [40–44] are of major interest: