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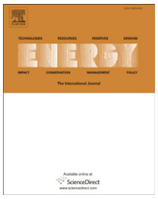

Numerical optimization of the occupancy rate of thermoelectric generators to produce the highest electrical power

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ABSTRACT

The electric power generated by thermoelectric modules obviously depends not only on the nature of the modules but also on heat transfers on both sides of these modules. In addition to the improvement of the thermoelectric material and module, analysis of thermoelectric systems is equally important in achieving their high-performance.

The aim of this study is to investigate the electric power extractable from a system equipped with thermoelectric modules and the influence of operating parameters on electricity generation. A computer model was developed to simulate the performances of the thermoelectric system. The influence of the position of the thermoelectric couples (occupancy rate) along the system was studied in order to optimize electrical power. The results obtained for modules made with Bi_2Te_3 from two various data sources and with slightly different thermoelectric properties are also presented in the study. Another study was made for automotive application. In this case, the use of various types of modules was considered. In each case the numerical model shows the importance of the repartition and choice of thermoelectric couples. It shows that for each thermoelectric fabrication there is an optimal occupancy rate which can vary greatly.

1. Introduction

TE (thermoelectric) devices directly convert thermal power to electrical power (Seebeck effect) and the opposite, electrical power to thermal power (Peltier effect).

Much research in recent years has focused on thermoelectricity to produce electricity. TEGs (TE generators) offer advantages such as high reliability, silence and low environmental impact and can use amounts of waste heat as an energy source in a simple and easy manner. Even if it has low energy conversion efficiency of around 2–5%, this technology is simple, robust, and has no moving parts [1]. Moreover, low efficiency is no longer the major issue when waste heat is recovered as a low-cost heat source.

Applications of TE generators are various. It is, for example, the case in the development of autonomous and maintenance-free sensors [2]. In both industrial processes and transportation, thermoelectricity can be used to exploit dissipated waste heat as electricity. The recovery of this waste heat (mainly exhaust gases), also known as energy harvesting, by means of thermoelectric generators is set to make a key contribution to the more efficient use of energy in the future [3].

Another attractive option is for providing small amounts of electricity to homes in developing countries, where currently about 1.6 billion people lack access to electricity [4,5].

TEGs are also used for cogeneration systems [3–5]. The goal in this case is not only to use heat to generate electricity but also for another objective, for example to produce hot water.

TEGs have many possible objectives but to be used industrially in a more efficient way, it is necessary to optimize them taking into account the specific features of each application.

In a classical thermoelectric generator, a heat exchanger captures the heat from the hot source and transfers this heat to the thermoelectric elements while another heat exchanger evacuates heat to a cold source in order to have a significant temperature gradient between the two faces of the TE elements. Various parameters affect the efficiency of a thermoelectric generator.

The main work consists in predicting the performance of TEGs with a particular configuration of heat exchangers and in studying

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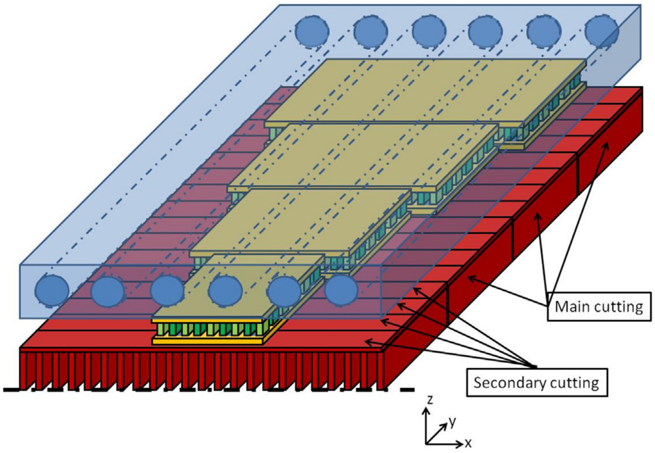

Fig. 1. Schematic diagram of the modelled thermoelectric generator (not in scale).

the effect of fluid flow rates, fluid properties and inlet temperatures on the power supplied by the system.

Numerous experimental studies [6,7] showed the influence of flow patterns, hot and cold temperatures, numbers of modules and geometry of the heat exchanger. The results obtained depend on the modules used, the type of heat exchanger and the operating conditions. So it seems pertinent to use modelling in order to optimize the whole thermoelectric system.

Most of the models combine the heat transfer equations and the standard thermoelectric equations including the Seebeck effect, Fourier effect and Joule effect. These models are qualified as standard models. Using this type of model, many studies [8] were carried out to simulate, for example, the type of heat exchangers [9–12], a specific geometry for aeronautics [13] and automotive [14] applications. Some numerical studies incorporate the Thomson effect [15–19] and show that this model is more accurate. For example, Nguyen and Pochiraju [20] solved a transient thermoelectric model that includes Seebeck, Peltier, Thomson, and Joule effects using finite-difference techniques to simulate the power generated from a TEG. The results showed that adding the Thomson effect plays a significant role in accurately predicting the power generated by the device. However, for optimization, the standard model is still good enough to obtain good accuracy and low calculation time.

TE material properties and heat exchanger performance are closely linked. When the variation of temperature is significant, the use of various types of TE modules is pertinent. For example, for temperatures above 330 °C, bismuth telluride becomes damaged. Espinosa et al. [21] studied a simple thermoelectric architecture composed of Mg_2Si/Zn_4Sb_3 (high temperature) followed by bismuth telluride materials (low temperature) along a given heat exchanger. They investigated the ideal proportion of required high-temperature materials. The number of thermoelements and electrical connections was addressed as well. Relevant engine operating points on a typical truck duty cycle were used as inputs in calculations to match actual engine conditions. They also discussed the influence of the connection of the module, presenting the case of all modules connected in series and then all modules connected separately. Kumar et al. [22] designed various efficient heat exchangers for automotive application also using a hybrid configuration (combination of bismuth telluride and skutterudite modules) to increase the system's electrical power output for the given thermal profile inside the TEG.

Although the interest of modelling in comprehension of the phenomena was demonstrated, little attention has been paid to the real optimization of the TEG.

Some optimizations have already been performed [23–25] but they do not take into account variations of the thermoelectric properties with temperature, whereas they could be significant under certain conditions.

The present paper focuses on a numerical study for optimizing the electric power extractable from a system equipped with thermoelectric modules. This system is a TEG whose hot source is a gas stream and whose cold source is a moving liquid. It was designed with typical configuration to easily understand the factors influencing TEG efficiency.

The electric power generated by TE modules obviously depends not only on the properties of the modules but also on heat transfers on both sides of these modules. So the position of the TE modules in the systems has an influence on electricity generation.

Some of our first results have already been presented [26] on the positioning of thermoelectric generators in order to produce the highest electrical power. The preliminary numerical results obtained for Bi_2Te_3 modules from two different data sources and with slightly different thermoelectric properties showed that the output electrical power is sensitive to the number and position of TE modules on the surface area of the heat exchanger. But these first

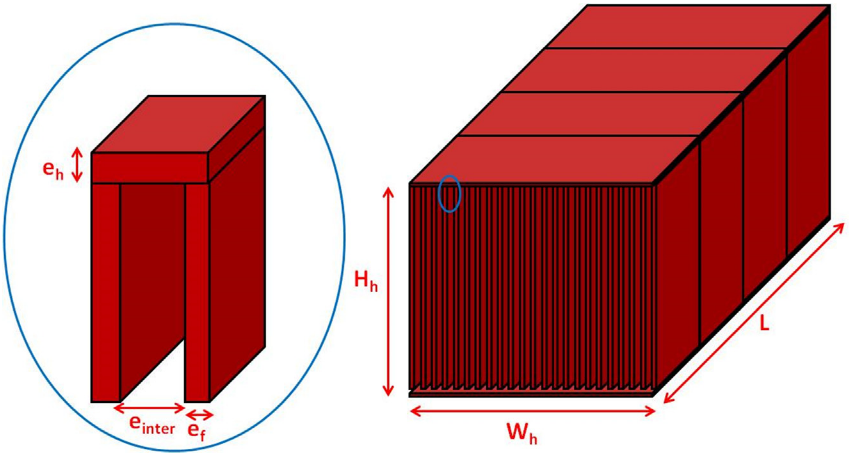

Fig. 2. Geometry of the hot heat exchanger.

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