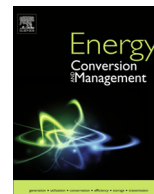




Contents lists available at ScienceDirect

Energy Conversion and Management

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

Experimental analysis with numerical comparison for different thermoelectric generators configurations

Camille Favarel^a, Jean-Pierre Bédécarrats^a, Tarik Kousksou^b, Daniel Champier^{b,*}^a Université Pau & Pays Adour, LaTEP – EA 1932, Laboratoire de Thermique, Energétique et Procédés, ENSGTI, Pau, France^b Université Pau & Pays Adour, Laboratoire des Sciences de l'Ingénieur Appliquées à la Mécanique et au Génie Electrique (SIAME), Pau, France

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Thermoelectric generator
Electricity production
Waste heat
Numerical simulation
Experimental validation

ABSTRACT

Thermoelectric (TE) energy harvesting is a promising perspective to use waste heat. Due to the low efficiency of thermoelectric materials many analytical and numerical optimization studies have been developed. To be validated, an optimization must necessarily be linked to the experience. There are a lot of results on thermoelectric generators (TEG) based on experiments or model validations. Nevertheless, the validated models concern most of the time one TE module but rarely an entire system. Moreover, these models of complete system mainly concern the optimization of fluid flow rates or of heat exchangers. Our choice is to optimize the number of these modules in a whole system point of view. A numerical model using a software for numerical computation, based on multi-physics equations such as heat transfer, fluid mechanics and thermoelectricity was developed to predict both thermal and electrical powers of TEG. This paper aims to present the experimental validation of this model and shows interesting experimental results on the location of the TE modules. In parallel, an experimental set-up was built to compare and validate this model. This set-up is composed of a thermal loop with a hot gas source, a cold fluid, a hot fin exchanger, a cold tubular exchanger and thermoelectric modules. The number and the place of these modules can be changed to study different configurations. A specific maximum power point tracker DC/DC converter charging a battery is added in order to study the electrical power produced by the TEG. The analysis of the influence of the number of thermoelectric modules and influence of electric currents on the produced electrical power was investigated. Different operating points of hot inlet gas airflow rate and of cold inlet source temperature were tested. Both experimental and numerical results show the necessity to optimize the position, the number of TE modules and the electrical currents.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Thermoelectricity appears to be one of the promising solutions to produce electricity from waste heat energy. Thermoelectric (TE) modules are maintenance free and have been tested in space since more than fifty years [1,2]. The first thermoelectric generator (TEG) was launched into space by the United States in 1961, aboard the Navy Transit spacecraft [3].

From the 1960s to the early 1990s the general technology situation had changed little in thermoelectric materials. Then, a key development happened with the first significant consumer product based on thermoelectricity: a thermoelectric picnic basket cooler introduced by Igloo [4]. At the same period, research impulsed

by Mildred Dresselhaus' group [5,6] created a renewed interest in thermoelectricity. From this point, the combined interest of the market demand and the scientific progress coupled with the constraints of current energy harvesting [7] led to the development of new thermoelectric generators. TEGs convert directly a part of the heat energy which crosses them into electricity. The main component of these devices is the TE module or Seebeck module (Fig. 1). TE modules usually contain some tens to hundreds of thermoelectric couples connected electrically in series and thermally in parallel. Other elements which surround this module, are however essential for an industrial use of the module: the heat exchangers which will increase the heat transfer through the modules and the electronic DC/DC convertors which will regulate the output voltage.

A TEG can be considered as a sort of heat engine that works by transferring energy from a hot source to a cold sink and converts a part of this heat into electricity.

* Corresponding author.

E-mail addresses: camille.favarel@ensam.eu (C. Favarel), jean-pierre.bedecarrats@univ-pau.fr (J.-P. Bédécarrats), tarik.kousksou@univ-pau.fr (T. Kousksou), daniel.champier@univ-pau.fr (D. Champier).

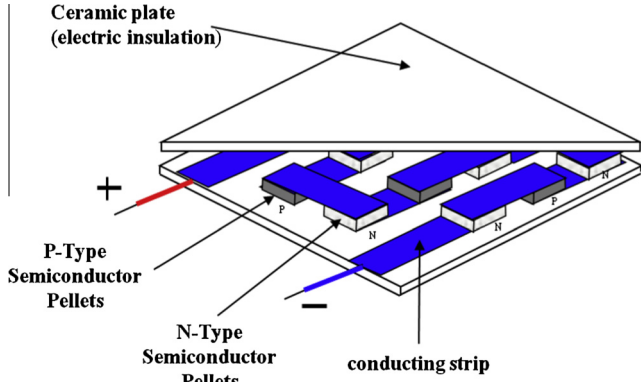


Fig. 1. Schematic of a TE module.

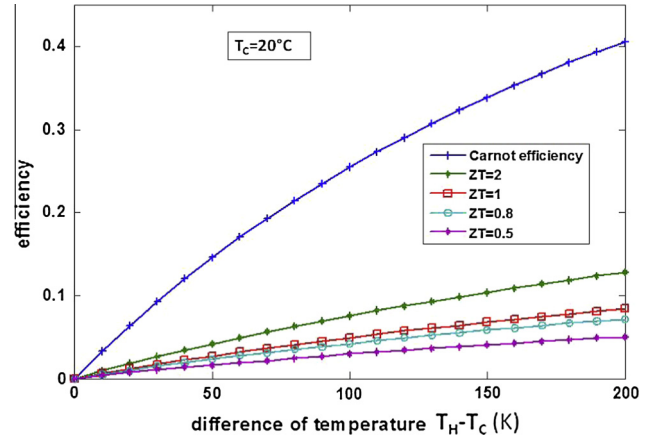


Fig. 2. Efficiency versus the difference of temperature.

The efficiency η_{TE} of a TE module, which is the ratio of the electrical energy produced (W_{elec}) on the heat (Q_H) reaching the hot side of the module, is given by the following formula [8,9]. This formula is obtained under the main following assumptions:

- the thermoelectric material properties are constant;
- the temperatures on each side of the module are uniform;
- the contact resistances, the parasitic losses are not taken into account.

$$\eta_{TE} = \frac{W_{elec}}{Q_H} = \frac{\Delta T}{T_H} \cdot \frac{\frac{m}{m+1}}{1 + \frac{(m+1)}{Z \cdot T_H} - \frac{\Delta T}{2 \cdot T_H \cdot (m+1)}} \quad (1)$$

With T_H the temperature of the hot side of the TE modules, T_C the temperature of the cold side of the modules, $\Delta T = T_H - T_C$ the temperature difference, m is the ratio of the electrical load resistance on the internal resistance of the TE module. Z is the factor of merit of the thermoelectric materials and can be expressed as a function of the electrical resistivities ρ_p and ρ_n , the thermal conductivities λ_p and λ_n and the Seebeck coefficients α_p and α_n of each of the two materials of the thermocouple.

$$Z = \frac{(\alpha_p - \alpha_n)^2}{(\lambda_p \cdot \rho_p)^{1/2} + (\lambda_n \cdot \rho_n)^{1/2}} \quad (2)$$

These material properties vary significantly with temperature especially for thermoelectric generation where the temperature gradient between the two faces of the TE module is very significant. For this reason, the expression of the efficiency should be used carefully.

However the maximal efficiency is obtained for an optimal ratio m_{opt} and yields [10]:

$$\eta_{TEmax} = \frac{W_{elec}}{Q_H} = \frac{\Delta T}{T_H} \cdot \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_C}{T_H}} \quad m_{opt} = \sqrt{1+ZT} \quad (3)$$

where T is the average temperature.

Despite the simplicity of the assumptions, this formula gives an estimate of the efficiency of a TEG. For preliminary calculation, it could be enough but for more accuracy, more sophisticated models exist which take into account the thermoelectric effects on the thermal resistance [11–13].

Fig. 2 shows the expected efficiency for different values of the figure of merit ZT . A commercially available Bi_2Te_3 module has a maximum figure of merit around 1. In laboratory, for bulk materials, it has been reported a figure of merit higher than 2 [14] but it will last a long time before TE modules will be commercially available. Production of modules in large quantities requires for

example to have a doped p-type material and a doped n-type material which are compatible, doping research, study of diffusion barriers and thermal expansion studies of the pellets. Due to the fact that the figure of merit is not constant but is a function of the temperature, it is more correct to take into account an average figure of merit. This average figure of merit is reasonably comprised between 0.5 and 0.8 for commercially available modules.

Fig. 2 clearly shows the low efficiency of the TE modules. However TE modules present other advantages (no moving parts, no working fluids, noiseless, need no maintenance and can work in any position) which compensate widely for their weak efficiency. TEGs become interesting generators in the case of recovering wasted heat for low production of electrical power (less than 1 kW) and in the case of radiant waste heat [15,16], where the use of other thermodynamic engines is not adapted.

Wasted heat is often in the form of a hot gas from a combustion process such as stoves [17], engine exhaust [18–21] or turbine nozzles [22].

The TEG is composed of multiple modules that are placed along a heat exchanger in which the hot gas circulates. The gas temperature changes along this exchanger and therefore the TE modules have different operating conditions. Numerical modeling is necessary to take into account the changes in temperature, changes in material properties as a function of temperature and to model the thermal losses and contact resistances as carefully as possible. Optimization of the TEG is required to compensate the poor efficiency of TE materials.

In thermoelectric (TE) optimization studies, there are a lot of results on thermoelectric generators (TEG) based on experiments or model validations. Nevertheless, the validated models concern most of the time one TE module [23–27] but rarely an entire system. Moreover, these models of complete system mainly concern the optimization of fluid flow rates [28], or heat exchangers [29]. Our choice is to optimize the location and the number of these modules in a whole system point of view. A numerical model pointing to the interest of optimizing the number of thermoelectric couples has been described in previous papers [30,31]. The study proposed here presents the results of an experimental TEG in three different configurations with different numbers of modules and compares them with the predictions of the numerical model. The originality of this work is to present the experimental comparison of three TEG configurations for different temperatures and different airflow rates. This comparison confirms the necessity of optimizing the number of thermoelectric modules and also shows a new result: the necessity of optimizing the layout.

Download English Version:

<https://daneshyari.com/en/article/7161568>

Download Persian Version:

<https://daneshyari.com/article/7161568>

[Daneshyari.com](https://daneshyari.com)