Thermoelectric generator from space to automotive sector- model and design for commercial and heavy duty vehicles

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Abstract

Despite the increase of alternative fuels for passenger cars, commercial and heavy duty vehicles continue to run on fossil fuel. The combustion engines used by these vehicles only convert around one third of the energy contained in the fuel into shaft power. The other two thirds are roughly dissipated equally into the exhaust gas and coolant. Given the high mass flow rates' characteristics for these vehicles a huge amount of energy is still expected to remain unused in the exhaust gas. This wasted energy presents a problem to be tackled in order to improve resource efficiency and CO_2 emissions. This master thesis proposes a thermoelectric generator (TEG) as a promising solution for this energy recovery. A TEG is based on the principle of the Seebeck effect and converts thermal energy into electrical power. A numerical model for a TEG was developed and applied to the exhaust gas system of both, a commercial and a heavy duty vehicle. Furthermore, a parametric study was performed on the influence of the heat exchanger's internal and external geometry. Herein the electrical and net output power were considered. Based on this data the TEG's system efficiency and TEG's recovery efficiency are calculated and discussed. Additionally, the geometric shape, particularly the thermocouple's leg height was analysed. The results obtained in this thesis allow the drawing of essential conclusions with regards to the overall TEG system performance which are essential to further studies.
Keywords: Waste heat recovery, Thermoelectric generator, Seebeck effect, Commercial and heavy duty vehicles, Heat exchanger

1. Introduction

In the automotive sector, particularly in the commercial and heavy duty vehicles, fossil fuels have assumed a position of undisputed leadership. Subsequently, this high fossil fuel consumption contributes to the expected fuel scarcity in the nearly future and to the undesired global warming effect. It is therefore imperative to analyse how the oil used by these vehicles can be utilized in a more efficient way. From the fuel energy consumed by these vehicles, only one third is converted by the engine in shaft power. The remaining two thirds of the fuel energy are wasted as heat in the exhaust gas and in the coolant system. Minimizing these energy losses would thus be a profitable way to improve fuel efficiency. In this context the thermoelectric generator (TEG) urges as a waste heat recovery technology. The TEG works on the thermoelectric principle, and converts thermal energy in electrical energy. When comparing to other environmentally friendly technologies the TEG presents distinctive advantages. Its biggest advantage is that it has neither moving parts nor refrigerators which makes the operation and maintenance of the whole system simple and less costly. TEGs also offer other major advantages, like the fact that they are extremely reliable, compact, light weighted and silent. The application of TEG as a waste heat recovery technology in the automotive sector gained relevance in their last 20 years. Since then with cooperation between industry and scientific community this technology is growing quickly with the goal to reach the industrial scale of production, since until now it is only in a prototype phase. In most recent years several studies were done on the improvement of the heat source also a significant number of studies were realized on the thermocouples. However, existing studies with reference to the overall TEG system are rare until now [1, 2, 3, 4]. Therefore, to fill this gap, this study presents a numerical model for a TEG. Subsequently, this numerical model is applied in the exhaust gas system of commercial and heavy duty vehicles. A parametric study on the heat exchanger and thermocouples are carried out to investigate their influence at a system level. The resulting performance from the TEGs of this parametric study are analysed and compared with each other.

2. Implementation

A thermocouple is the main building block of a thermoelectric generator. It is composed of a pair of p-type and n-type semiconductor legs which are connected at least at one point. Multiple legs of p-doped and n-doped semiconductors are connected electrically in series and thermally in parallel to form a thermoelectric module. To connect the multiple legs, electrical conducted strips are used. In addition, to ensure electrical insulation and structural support of the thermoelectric module, ceramic strips are used, as represented in figure 1. This structure is sandwiched between a hot side and a cold side.

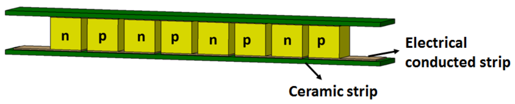

Figure 1: Thermoelectric module design and ceramic plates.

2.1. Thermoelectric generator design

Not available.

2.2. Modelling thermal behaviour of the thermoelectric module

Not available.

2.3. Modelling electrical behaviour of the thermoelectric module

Not available.

2.4. Modelling of the entire thermoelectric generator

Not available.

2.5. Numerical approach

Not available.

3. Case study

Within the automotive industry there are several ways to categorize vehicles. In this work the vehicles' weight class is considered. Based on the European regulations, the vehicle class N was selected as target study. Within this class two vehicles were selected for the application of the TEG: vehicle A with 3.5 tonnes and vehicle F with 40 tonnes. Subsequently, to obtain the required input parameters to apply to the numerical TEG model, vehicle A and F were simulated on an vehicle simulator named ADVISOR [10]. Herein only the most important results are summarized in the table 1.

Table 1: Simulation output results for vehicles A and F and their respective boundary conditions.
Not available.

4. Results

In this section the numerical model developed for the TEG in section 2 is applied on the exhaust gas from the vehicles presented in section 3.

4.1. Potential analysis

Not available.

4.2. Parametric study on the heat exchanger

Not available.

4.3. Analysis of the thermocouple

Not available.

5. Conclusions

Not available.

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