Automotive waste energy recovery with thermoelectric generators

Octavio Armas[a,1], Pablo Fernández-Yáñez[2], Reyes García-Contreras[3], and Carmen Mata[4]

[1-3]School of Industrial and Aerospace Engineering, University of Castilla - La Mancha (UCLM), Av. Carlos III, s/n, 45071, Toledo, Spain
[4]School of Mining and Industrial Engineering, University of Castilla - La Mancha (UCLM), Almadén, Spain

Thermoelectric generators arise as an option to recover part of the great amount of energy wasted as heat in the exhaust systems of internal combustion engines. Results of fuel savings with diesel and gasoline engines are provided.[b]

In internal combustion engines, about a third of the fuel energy intake is wasted through the exhaust system. Recovering part of this energy could save fuel and reduce emissions in passenger and commercial vehicles. Among the most well-known technologies to turn waste thermal energy into electrical energy, the most well-known are: Organic Rankine Cycles (ORC), electric turbo-generators (eTG) and thermoelectric generators (TEG). For light-duty vehicles, ORC has the drawbacks of high weight and high space necessity, leaving eTGs and TEGs as the most viable options. TEGs (see Fig. 1) convert thermal energy into electrical energy using the Seebeck effect.

Figure 1: Experimental setup with TEG circled in white [1].

A TEG was designed using CFD numerical simulations with the target of maximizing the electrical output while minimizing the extra pumping work caused [2]. The prototype was coupled to the exhaust system of a light-duty diesel engine.

Nine stationary points (A to I, see Fig. 2) representative of the real driving area of the engine map were selected for experimental tests. Results show that up to 0.56% of energy savings could be obtained [3].

In addition, a comparison between TEGs and eTGs in a light-duty gasoline engine was made. The main disadvantage of eTGs was identified: during common driving conditions, they produce a very high pressure drop that overcomes the electrical production, leading

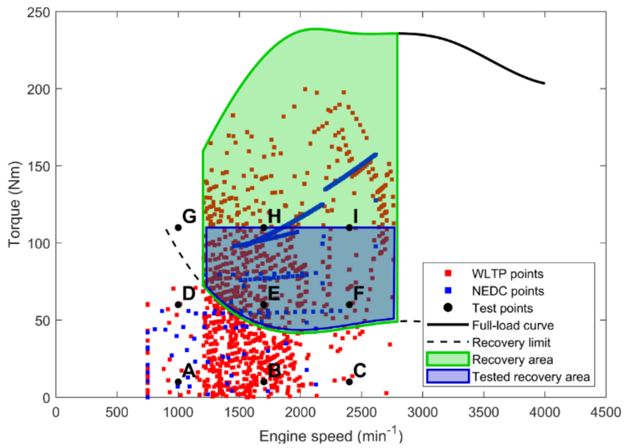

Figure 2: Steady test points selected based on New European Driving Cycle (NEDC) and World Harmonized Light-duty Vehicle Test Procedure (WLTP) driving tests.

even to negative net power production [3]. In addition, eTGs need more underhood space.

Findings indicated that up to a 1.1% of fuel savings can be obtained from a TEG in real driving conditions for a light-duty gasoline engine [3].

These results pointed TEGs as the path to follow to recover energy in light-duty engines. In addition, from the assembly point of view, the TEGs can be integrated nearer the end of the exhaust system, having more potential to be implemented in the underbody of cars.

In another work [4], it was determined the potential for energy recovery from exhaust gases with thermoelectric generators in a passenger car using three fuels (diesel, gas-to-liquid, and biodiesel) at different altitudes (20, 625 and 2300 masl). The potential for energy recovery was found always higher under extra-urban driving conditions at all altitudes tested due to the higher engine load and, consequently, higher temperatures and gas mass-flow rates reached. This result was particularly noticeable at high altitudes, where the EGR valve is usually closed.

The influence of the TEG on the energy fluxes in a diesel engine was also analized. The addition of a TEG causes modifications in the distribution of the energy fluxes in an engine, altering the global energy balance and its efficiency (see Fig. 3). Regarding its integration in vehicles, a TEG could be active during all driving conditions. The TEG causes a mild improvement on the efficiency of the engine due the low efficiency of current thermoelectric materials. At middle engine loads, the exhaust energy is enough to produce enough energy to overcome the increase in pumping work, which translates into an increase in the efficiency of the engine. At low loads, the electrical production is almost null, but in exchange the pressure losses are the same, not causing penalties in the global efficiency when the device is not active. It was found that, within the limits of common engine conditions, the engine torque has more influence than the engine speed.

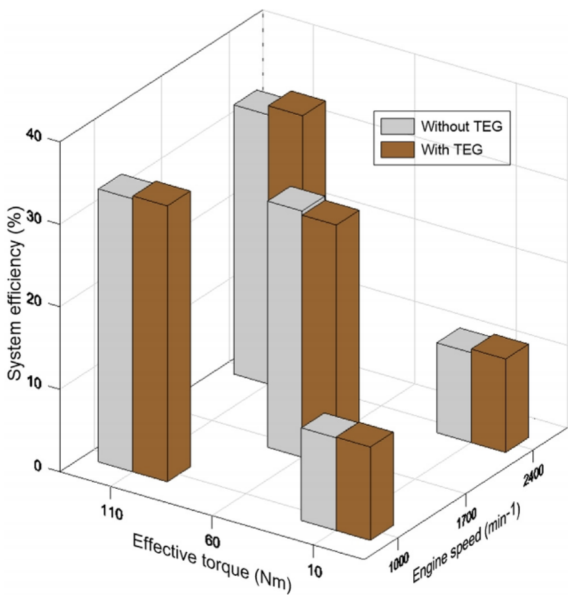

Figure 3: Change in global efficiency of a 2L diesel engine with and without a TEG [5].

Conclusions

Estimations of the production of current commercial thermoelectric modules lead to electrical gross power values of 480 W at full load conditions with a TEG composed of 80 thermoelectric modules (see Fig. 4). For essential electric consumers of a vehicle, an average of 300 W is needed (around 1 kW if we include other long-term electric consumers). With further development, a TEG could be a substitute of the inefficient engine-alternator system.

Concerning waste energy recovery with TEGs, three main areas of research have been identified: improving the properties of thermoelectric materials, reducing the exhaust gas convection thermal resistance and adapting the commercial thermoelectric modules to the exhaust temperature range in internal combustion engines of road vehicles [6]. Our current work focuses on the latter two, combining experimental tests with numerical simulations.

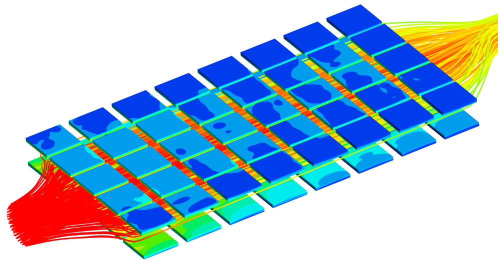

Figure 4: CFD numerical simulation of a TEG. The inside hot exhaust gas and the thermoelectric modules are shown.

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Notes

a. Email: octavio.armas@uclm.es

b. The following researchers also participate in this work: Dr. José A. Soriano, Dr. Arantzazu Gómez and Dr. Luis Sánchez-Rodríguez from UCLM and researchers from University of Jaén.

References

[1] S. Ezzitouni, P. Fernández-Yáñez, L. Sánchez, O. Armas, F. Soto, Effect of the use of a thermoelectric generator on the pumping work of a diesel engine. *International Journal of Engine Research* **22(3)** (2021) 1016-1027

[2] P. Fernández-Yáñez, O. Armas, A. Capetillo, S. Martínez, Thermal analysis of a thermoelectric generator for light-duty diesel engines. *Applied Energy* **226** (2018) 690-702

[3] P. Fernández-Yáñez, O. Armas, R. Kiwan, A.G. Stefanopoulou, A.L. Boehman, A thermoelectric generator in exhaust systems of sparkignition and compression-ignition engines. A comparison with an electric turbo-generator. *Applied Energy* **229** (2018) 80-87

[4] R. García-Contreras, A. Agudelo, A. Gómez, P. Fernández-Yáñez, O. Armas, A. Ramos. Evaluating thermoelectric modules in diesel exhaust systems: potential under urban and extra-urban driving conditions. *Energies* **12** (2019) 1105

[5] S. Ezzitouni, P. Fernández-Yáñez, L. Sánchez, O. Armas, Global energy balance in a diesel engine with a thermoelectric generator. *Applied Energy* **269** (2020) 115-139

[6] P. Fernández-Yáñez, A. Gómez, R. García-Contreras, O. Armas, Evaluating thermoelectric modules in diesel exhaust systems: potential under urban and extra-urban driving conditions. *Journal of Cleaner Production* **182** (2018) 1070-1079