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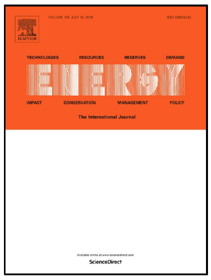

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Kévin Rosset, Violette Mounier, Eliott Guenat, Jürg Schiffmann

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Kévin Rosset*, Violette Mounier, Eliott Guenat, Jürg Schiffmann

kevin.rosset@epfl.ch, violette.mounier@epfl.ch, eliott.guenat@epfl.ch, jurg.schiffmann@epfl.ch

Ecole Polytechnique Fédérale de Lausanne, Laboratory for Applied Mechanical Design,
Rue de la Maladière 71b, 2002 Neuchâtel, Switzerland

* Corresponding Author

ABSTRACT

Waste heat recovery from passenger car internal combustion engines by means of an organic Rankine cycle (ORC) system is promising for reducing CO_2 emissions. In this study, different cycle configurations capable of converting waste heat from both coolant and exhaust gases are investigated based on different working fluid categories. Radial-inflow turbines are considered as expansion devices and corresponding isentropic efficiencies are evaluated based on a preliminary design map accounting for the effect of the pressure ratio. Mechanical losses resulting from the use of a gas-bearing-supported rotor driving a permanent magnet generator are also evaluated. In order to identify the turbo-ORC system design tradeoffs, constrained multi-variable and multi-objective optimizations are performed using an evolutionary algorithm. It is found that the optimal cycle configuration and working fluid depend on the available space in the vehicle and that the condenser is the most critical component for the ORC system integration. In addition, the most suitable working fluids for this application are characterized by (1) a boiling point close to the heat sink temperature, (2) a high critical pressure, and (3) a high molecular weight. The resulting optimal radial-inflow turbines are 10-33 mm in tip diameter and operate at 80-330 krpm.

Keywords: internal combustion engine, waste heat recovery, organic Rankine cycle, turbo-generator preliminary design, heat exchanger sizing, multi-objective optimization

1. Introduction

Growing concerns about fossil fuel shortage and global warming advocate for a more rational use of primary energy. Currently, the transportation sector consumes 20% of the worldwide primary energy supply, while depending mainly (92%) on fossil fuels [1]. As a consequence, this sector is also responsible for 24% of the worldwide CO_2 emissions from fuel combustion, including 75% from road transports [2]. In the European Union, passenger cars account for 87% of the total road vehicle fleet while producing 64% of the associated CO_2 emissions [3]. These high levels of emissions result from the low fuel-to-wheel efficiency of vehicles propelled by internal combustion engines (ICE), i.e. typically 15-31% [4]. There is consequently a strong potential for energy savings and emission reductions by improving the efficiency of ICE-powered road vehicles. Such improvements can be achieved by (1) decreasing the vehicle power requirements, (2) improving the efficiency of the power transmission train, and (3) integrating advanced engine technologies [5]. In order to encourage innovations for cleaner vehicles, the European Union gradually imposes "emission performance standards" to vehicle manufacturers, with the ultimate goal of reducing the average CO_2 emissions of passenger cars to 95 g/km by 2020 [6]. In the recent years, waste heat recovery (WHR) technologies have been investigated in order to further increase the efficiency of ICE-powered vehicles. Indeed, for a given fuel input, two thirds of the energy is lost as heat in the engine coolant and exhaust gases [7]. Among engine WHR technologies, Organic Rankine Cycle (ORC) systems offer the most attractive combination of simplicity, component cost and efficiency, with a fuel economy improvement potential around 10% and a payoff time within 2-5 years [8].