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Dynamic Modeling of an Organic Rankine Cycle to recover Waste Heat for transportation vehicles

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Abstract

According to the International Council on Clean Transportation, the target for CO_2 emissions in passenger cars was reduced until 2007 an average of 1% per year, however from 2008 more restrictive targets were imposed with an average of 4% per year. In 2020 the target of CO_2 emissions for passenger cars and light-commercial vehicles will be reduced from 2012 up to 28% and 18%, achieving values of 95 g/km and 147 g/km respectively. Therefore, waste heat recovery technologies seem to assume an essential role in the CO_2 reductions of the forthcoming decade. This paper deals with a 1D simulation model of an Organic Rankine Cycle coupled to a 2 l naturally aspirated gasoline engine and using ethanol as working fluid. The novelty of this model is based on the possibility to obtain performance parameters of the dual system Internal Combustion Engine-Organic Rankine Cycle. An experimental facility of an ethanol ORC using a swash-plate expander coupled to gasoline engine has been used to calibrate it.

Keywords: Waste Heat Recovery, Organic Rankine Cycle, Amesim, NEDC, Dynamic modeling

1. Introduction

Regulations for ICE-based transportation in the EU seek carbon dioxide emissions lower than 95 g CO_2/km by 2020 [1]. In order to fulfill these limits, improvements in vehicle fuel consumption have to be achieved. One of the main losses of ICEs happens in the exhaust line [2]. Internal combustion engines transform chemical energy into mechanical energy through combustion; however, only about 15 - 35% of this energy is effectively used to produce work [3]. The remaining 65 to 85% of the fuel energy is rejected as waste heat to the environment through exhaust gases (22 to 46%) and the radiator (18 to 42%) [4], which evacuates the heat from the Charge Air Cooler (CAC), Exhaust Gas Recirculation (EGR) and cooling loop. Therefore, these sources can be exploited to improve the overall efficiency of the engine [5]. Between these sources, exhaust gases show the largest potential of Waste Heat Recovery (WHR) due to its high level of exergy [6]. Regarding WHR technologies, Rankine cycles are considered as the most promising candidates for improving Internal Combustion Engines [7]. However, the implementation of this

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technology in modern passenger cars requires additional features to achieve a compact integration and controllability in the engine [8]. While industrial applications typically operates in steady state operating points, there is a huge challenge taking into account its impact in the engine during typical daily driving profiles [9]. The main objective of this paper is to illustrate the fuel saving reduction potential and capabilities offered by the interaction between an Internal Combustion Engine and Organic Rankine Cycle by using the LMS Imagine.Lab Amesim platform.

Nomenclature

bsfc	Brake Specific Fuel Consumption [g/kWh]
NEDC	New European Driving Cycle
ORC	Organic Rankine Cycle
WHRS	Waste Heat Recovery System

2. System Layout

An ORC test bench was designed and built at CMT-Motores Térmicos in Polytechnic University of Valencia in a research project with the companies Valeo Systèmes Thermiques and Exoès. This facility can be coupled to different types of automotive combustion engines (an automotive diesel engine, a heavy duty diesel engine and an automotive petrol engine). The test bench recovers energy from exhaust gases of a gasoline engine and exchanges thermal energy to the ethanol side Figure 1.

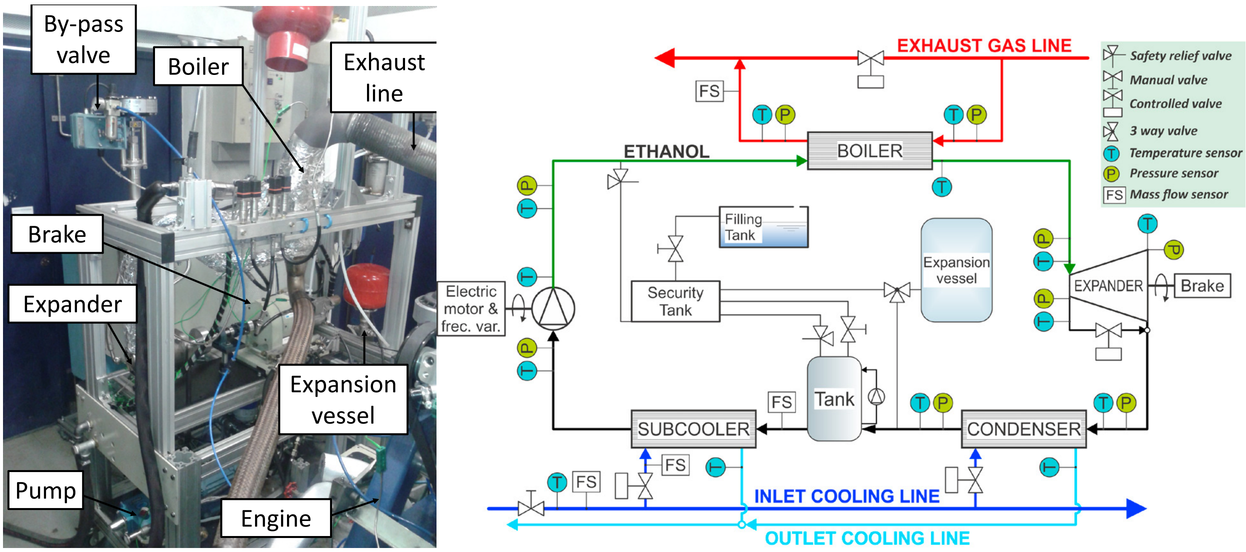

Fig. 1. Experimental ORC installation

3. Modeling

A comprehensive model of the Organic Rankine Cycle using LMS Imagine.Lab Amesim platform is described on this paragraph. The software package provides a 1D model suite to simulate and analyze multi-domain intelligent systems, and to predict their multi-disciplinary performances. This software consists of available object-oriented libraries, where the user should connect them properly and fix the parameters. A simplified layout of the ORC facility consisting of a boiler, a pump, a volumetric expander, a fluid receiver, a condenser, an expansion vessel and by-pass valve is considered in this model. A 0D discretization model with different small volumes of both elements (boiler