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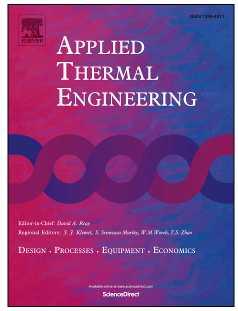

A comprehensive design methodology of organic Rankine cycles for the waste heat recovery of automotive heavy-duty diesel engines

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A comprehensive design methodology of organic Rankine cycles for the waste heat recovery of automotive heavy-duty diesel engines

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ABSTRACT

One of the most promising approaches to recover the waste heat from internal combustion engines is the Organic Rankine Cycle owing to its efficiency and reliability. The design optimization of ORC, however, is nontrivial because there exist many design variables and practical considerations. The present paper proposes a comprehensive design methodology to optimize the Organic Rankine Cycles (ORC) considering a wide range of design variables as well as practical aspects such as component limitations and costs. The design process is comprised of three steps: heat source selection, candidate fluid selection, and thermodynamic cycle optimization. In order to select the best waste heat source, the available energy and other practical considerations of various heat sources have been compared. Among others, the Exhaust Gas Recirculation (EGR) cooler is found to be the best heat source, and thus used for the rest of this study. Based on a systematic working fluid analysis, Ethanol, Pentane, and R245fa are selected as three candidate fluids. For the comprehensive ORC optimization, four types of cycle layouts are considered; 1) subcritical cycle without a recuperator, 2) subcritical cycle with a recuperator, 3) supercritical without a recuperator, and 4) supercritical cycle with a recuperator. Four cycle layouts coupled with three candidate fluids give a total of twelve cycle analyses. Results show that the best performance is provided by the regenerative subcritical cycle with Ethanol, while the solution with minimum capital cost is the subcritical cycles with Ethanol but without a recuperator.

1. Introduction

Despite the substantial improvements of diesel engine efficiency over the last few decades, a considerable amount of energy is still rejected to the ambient [1]. These losses, depending on engine operating conditions, are in the order of 50% of fuel energy [2]; thus a significant margin of improvement on the total system efficiency is still available. Over the last decade, a number of different technologies have been proposed and evaluated by both industry and academia [3]. One of the most promising technologies that seem to collect a lot of attentions, especially in the field of heavy duty engines, is to recover the waste heat with a bottoming organic Rankine cycle (ORC).

The ORC is considered one of the most practical and promising solution because the thermodynamic systems have a long history, and thus well understood, cost effective, and reliable. In fact, the ORC has already been used for large applications such as factories to recover the waste heat rejected during manufacturing processes [4]. Nevertheless, the ORC for on-road applications give rise to new challenges and engineering problems due to the mobile nature of automotive internal combustion engines (ICE). For instance, one of the early stage decisions that need to be made is the identification of the best heat source among the various available. Unlike industrial applications, ICEs have multiple waste heat sources that are characterized by different properties, so energy analyses would be necessary to select the best source. Another important factor that need to be considered during the design of a WHR system for vehicles is the system cost [5]. The waste heat available and the power produced of ICEs are much smaller than those of industrial plants. Thus, the global cost of the system plays a more meaningful role. To further complicate the problem, practical aspects of the design such as size are also important, and many design variables of the Rankine cycle have influences on them. For example, the type of working fluid and maximum pressure are strongly coupled with both performance, size, and cost, and thus these design variables and their influences on both performance and practical aspects need to be considered for the proper design optimization.

Despite the importance of these design considerations, most of the foregoing works tend to focus on one aspect of the system design; fluid selection or cycle optimization, rather than optimizing the WHR system considering a wide-range design methodology that includes performance, cost, and dimensions criteria. For instance, Teng et al. in [2], [5] and [6] studied working fluid selection for ORC-WHR and designed various types of Rankine cycles for each waste heat source. However, their variables and parameters are more based on common practices rather than real evaluations and optimizations. Another study by Chen et al. focused on selecting the best working fluid for low-grade heat sources [7]. They investigated a wide range of working fluids and concluded that the choice of the working fluids depends on many parameters and on the heat source considered. Therefore, the choice of the heat source is the first