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HD Diesel engine equipped with a bottoming Rankine cycle as a waste heat recovery system. Part 2: Evaluation of alternative solutions

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ABSTRACT

A theoretical investigation has been performed on the feasibility of introducing a waste heat recovery (WHR) system in a two-stage turbocharged HDD engine. The WHR is attained by introducing a Rankine cycle, which uses an organic substance or directly water as a working fluid depending on energetic performance considerations. A previous research was carried out to evaluate the maximum potential of this WHR concept, a conventional layout was used for coupling the Rankine cycle to the thermal engine. The objective of the present research is to broad the scope of the previous analysis by considering new alternative solutions for the problems related to the coupling between the WHR Rankine cycle and the thermal engine. These solutions are based on adapting one of the turbochargers by removing its turbine and trying to recover the energy by the Rankine cycle. Finally, the turbine of the Rankine cycle supplies the recovered energy directly to the compressor of this turbocharger. Thus, in these layouts the coupling is simpler as it involves only two turbomachines, which are supposed to share a similar rotating speed. From the results of the global energy balance, these alternative layouts produce slight benefits in fuel consumption but in all cases these benefits are lower compared to those attained with conventional layouts.

1. Introduction

The main advantage of direct injection Diesel engines is its high thermal efficiency. This competitive efficiency together with its high reliability makes the direct injection Diesel engine particularly suitable as a power plant for heavy-duty transport applications. Promoted by the increasingly strict regulations on pollutant emissions [1], the Diesel engine is being object of intense research to make it more environmentally friendly, especially regarding NOx and particulate matter. An attractive alternative for improving the overall thermal efficiency of Diesel engines consists of recovering the energy lost by means of a waste heat recovery (WHR) system.

Hountalas et al. performed a theoretical analysis comparing the most common WHR systems, including mechanical and electrical turbocompounding together with a bottoming Rankine cycle [2]. From the reported results, a reduction in fuel consumption up to 8–9% at full engine load is feasible.

In a previous stage of the present research and in other works available in the literature have been stated the benefits in terms of fuel consumption produced by the bottoming Rankine cycle strategy [3,4]. Two different approaches were investigated, two Rankine cycles in cascade (binary cycle), and a single Rankine cycle neglecting the low temperature sources. The reduction in fuel consumption without considering internal irreversibilities ranged from 16% in the first configuration to 8.5% in the second configuration. Similar results have been reported in the literature regarding a potential decrease in fuel consumption of approximately 10% attainable by integrating a bottoming cycle [5].

However, most of the literature limited its scope to the energy flow analysis, omitting any reference about how to reintroduce the recovered energy into the Diesel plus Rankine engine power plant. The main alternatives consist of directly linking the turbine shaft with the crankshaft or converting the mechanical power into electrical power to make it suitable for its use [6]. The layout of the first alternative, although seemingly straightforward, is not easy to develop due to the extreme differences in rotation speed between the turbine and the Diesel engine, while the second solution requires an electrical generator and also a set of batteries to store the energy [7] aside from the complexity in development the required turbine or expander for ORC or steam bottoming cycles.

Considering the different Diesel engine subsystems, there is one turbomachine rotating at similar speed as that of the bottoming cycle turbine, the compressor. Therefore, the power produced by the Rankine cycle turbine could be directly used to drive the

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