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A zero-dimensional model for simulation of a Diesel engine and exergoeconomic analysis of waste heat recovery from its exhaust and coolant employing a high-temperature Kalina cycle

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ABSTRACT

An exergoeconomic assessment is performed for a high-temperature Kalina cycle which is proposed to produce power from a Diesel engine exhaust and coolant. Developed zero-dimensional model for the engine simulation revealed its parameters as well as the influences on the thermodynamic and exergoeconomic parameters of the waste heat recovery system of the engine speed. Moreover, the system responses to the changes of the Kalina important parameters are assessed. Examining the locations of pinch point temperature differences in the system heat exchanging devices showed a proper thermal matching because of using a zeotropic working fluid. Results showed that the proposed cycle could produce 21.74 kW power from the waste heat recovery process, which is significant for a 98.9 kW engine. Energy and exergy efficiencies are also calculated to be 25.55% and 55.52%, respectively, and unit cost of the produced power in the Kalina turbine is measured as 15.52 cent/kWh, for a specific considered condition. The parametric study revealed a rise in the system produced power with the engine speed. Moreover, it is found that the produced power unit cost, as well as the system total cost, is reduced with increasing the turbine inlet temperature and pressure.

1. Introduction

Internal Combustion Engines (ICEs) are the primary choices for small scale power generation purposes as well as agricultural/industrial machines and vehicles due to their promising features such as high thermal efficiency, reliability and low maintenance [1]. ICEs are sources of environmental pollution and fuel consumption so that almost 60–70% of the industrial countries fossil fuel is used by ICEs [2]. The efficiency of large engines is higher than the small ones and can reach up to 42–48% [3]. Despite efforts to increase the engine efficiency in the recent years, more than 50% of the consumed fuel energy is still wasted in a typical ICE mainly through engine cooling system and exhaust gas [4]. Reuse of the exhaust gas and cooling system waste heat is one of the effective methods to improve engine performance and decrease fuel consumption and environmental pollution.

Different Waste Heat Recovery (WHR) techniques are suggested to use the engine waste heat [5]. As a promising method, several researchers employed the Organic Rankine Cycle (ORC) to produce power from the engine waste heat [6]. Zhao et al. [7] made a comprehensive analysis for an ORC to generate power from a Diesel engine exhaust gas, in which, different conditions are considered to assess operation modes of the system. A genetic algorithm and an artificial neural network are employed to determine the system optimum parameters. The analysis revealed that the WHR process increases the system efficiency and decreases the brake specific fuel consumption about 3.57% and 10.09 g/kWh, respectively. Guillaume et al. [8] proposed an ORC for the WHR from a truck engine exhaust gas. A radial inflow turbine is used in this experimental study, and performance of the system is investigated for R1233zd and R245fa working fluids. The components performance is compared considering the same temperature levels, the same condensing temperature and evaporating pressure and the same pressure levels, in three scenarios. The assessment showed that R1233zd has better performance compared to R245fa. Yang and Yeh [9] performed a thermodynamic and economic analysis for the WHR process from the exhaust of a marine engine using an ORC. They examined several working fluids and concluded that the ORC with R245fa has the best economic parameters, while R1234ze shows the best thermodynamic performance. Shi et al. [10] presented a review paper on the WHR from ICEs using ORCs. High-temperature ORCs, mixture ORCs and ORCs with extra loops have been the focus of attention.

The isothermal phase change of the pure fluids leads to a significant temperature difference in heat exchangers of the ORCs with pure fluids.

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