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# Simulation of an Exhaust Heat Driven Rankine-Cycle for Heavy-Duty Diesel Engines

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**Abstract**

High-efficiency vehicle engines play an important role in the context of low-carbon cities. An auspicious approach to reduce the emissions of internal combustion engines and make them more fuel efficient is exhaust heat recovery by an Organic Rankine Cycle (ORC). The present study focuses on the simulation of ORCs for exhaust heat recovery in heavy-duty diesel engines for mobile applications, e.g. trucks, rail vehicles and ships. An exceptional challenge associated with these applications are variable engine load profiles, causing the partial load operation of the ORC to gain significant importance. Furthermore, the different system components are highly depending on another. Hence optimizing a single part of the ORC does not necessarily lead to an improvement of the overall system. The level of detail of the simulation models has a considerable influence on their ability to reflect and predict the real operating performance of the system. While rather simple potential analyses promise the capability to recover large amounts of heat, detailed simulation models of a first prototype predict significantly lower recovery rates. Still, the simulation results confirm the process feasibility with fuel savings and therefore emissions reductions of up to 3%.


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*Keywords:* Organic Rankine Cycle; Exhaust Heat Recovery; Diesel Engine; Waste Heat; Simulation

## 1. Main text

In times of depleted petroleum supplies, greenhouse effect and stringent environmental emission regulations, it is an important challenge to improve the efficiency of internal combustion engines. About one third of the fuel-bound energy gets lost through waste heat in the exhaust gas, which makes the recovery

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of exhaust heat an auspicious approach to improve the efficiency of internal combustion engines and to lower their emissions. This study focuses on the simulation of ORCs for exhaust heat recovery in heavy duty diesel engines in trucks, rail vehicles and ships. Simulation results provide a basis for potential analyses and the dimensioning of system components.

**Nomenclature**

*Abbreviations*

| | |
|---|---|
| ORC | Organic Rankine Cycle |

*Symbols*

| | |
|---|---|
| $c$ | rotational speed [m/s] |
| $\dot{H}$ | enthalpy rate difference [kJ/kg] |
| $p$ | pressure [Pa] |
| $s$ | entropy [kJ/(kg K)] |
| $T$ | temperature [K] |
| $\eta$ | efficiency [-] |

*Subscripts*

| | |
|---|---|
| in | inlet |
| is | isentropic |
| out | outlet |

## 2. System description

In an earlier investigation a comparative assessment of different cycle processes for exhaust heat recovery was carried out. As a result, the ORC was found to be the most promising option. Furthermore, ethanol as working fluid turned out to have the most advantageous properties for this specific case of application. [1]

### *2.1. System Constraints*

Regardless of the system design, the power output of the ORC and thus the achievable fuel savings are limited by some substantial restrictions like the available exhaust heat and recooling power, the temperature of the heat sink, the packaging and limited space for the system components or a minimum tolerable exhaust gas outlet temperature to avoid acid condensation.

A further challenge associated with heavy-duty diesel engines in mobile applications are highly variable engine load profiles, resulting in fluctuating exhaust temperatures and mass flow rates and thus in an unsteady heat source for the ORC. For this reason, the ORC should not be designed for one specific engine