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Recovery of exhaust and coolant heat with R245fa organic Rankine cycles in a hybrid passenger car with a naturally aspirated gasoline engine

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ABSTRACT

In internal combustion engines, only a part of the fuel energy flow is transformed into power available at the crankshaft, while the most part of the fuel energy flow is lost as coolant, exhaust gases and other waste heat flows. Recovery of waste heat from the exhaust gases, and the coolant with organic Rankine cycles (ORC) is considered here for a hybrid vehicle powered by a 1.8 L naturally aspirated gasoline engine. The ORC systems fitted on the exhaust and the coolant permit an increase in fuel conversion efficiency by up to 6.4% and 2.8% individually, and by up to 8.2% combined. The average improvements all over the map are 3.4%, 1.7% and 5.1% respectively. These gross improvements do not account for the less than uniform efficiency of the mechanical-to-electric-to-chemical-to-electric-to-mechanical loop when the ORC expanders are used to charge the battery of the hybrid vehicle. Nor do they account for the reduced efficiency of the thermal engine due to the back pressure effects on the indicated mean effective pressure (exhaust ORC) and friction mean effective pressure (coolant ORC). Nevertheless, these values serve as a reference point for the assessment of the current potential of a technology that is still being developed having major downfalls in the increase of weight, costs, packaging complexity and finally in difficulty in transient operation.

1. Introduction

In internal combustion engines, only a small part of the fuel energy flow is transformed into power available at the crankshaft. For the best points of operation, diesel engines have a maximum efficiency approaching 45% while gasoline engines have efficiencies of about 35%. For both engines, the most part of the fuel energy flow is therefore lost as coolant heat flow and exhaust gases heat flow. In everyday operating conditions, cars have average engine efficiencies on driving cycles well below their top values, with the heat flow lost in the exhaust gases and the engine coolant increasing accordingly. In many driving conditions, the waste heat flow represents an important part of the fuel energy flow. The energy flow potentially available to be converted to usable power in the exhaust gases and the coolant is therefore quite significant. For that reason many projects are being carried out by various original equipment manufacturers, their suppliers and research centers and universities to increase the efficiency of internal combustion engines using technologies to convert the waste heat flow to electrical or mechanical energy [1–17].

There are a range of systems that have been announced as having the capacity to efficiently regenerate the waste heat flow, with some systems existing already and several more currently under development. The organic Rankine cycle (ORC) is certainly one of the most promising technologies for recovery of the waste heat in automotive applications [9–17]. We therefore considered the ORC worthy of further investigation; at the very least, extended computation undertaken to recover the coolant heat. In addition to the engine specific references [9–17], other information about ORC can be found in recent papers [18–27].

2. Exhaust gas and coolant heat regenerations

The ORC is a thermodynamic cycle, according to the Rankine principle, but specifically uses organic liquids/gases in order to have a boiling point at relatively low temperatures. The heat is used to make the liquid boil and generate high pressure gases that will then drive a motor that is able to transmit torque to the crankshaft. There is the option to use a turbine or a reciprocating piston as the expander of the Rankine cycle. Among the liquids for the organic Rankine cycle *Genetron® 245fa* [28] is one of the preferred contemporary approaches. It is a non-chlorinated hydro fluorocarbon, non Ozone depleting liquid with a low global warming

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