ARTICLE INFO
Article ID: 03-15-06-0045

doi:10.4271/03-15-06-0045

Fuel-Economy Performance Analysis with Exhaust Heat Recovery System on Gasoline Engine

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Abstract

As the electrification and connectivity technologies penetrate the market, the opportunities for intelligent thermal management of the vehicles become more salient. When an exhaust gas heat recovery (EGHR) system is used to recover waste heat from gasoline engine exhaust, the thermal parameters of the exhaust gas vary greatly, and these influence the performance of the heat exchanger (HE) system. To improve the recovery of exhaust waste heat and its conversion to faster coolant warm-up and cabin heating performance effectively, the heat transfer evaluation and optimal performance analysis are conducted on different EGHR system designs with different exhaust thermal parameters. This study aims at analyzing the fuel economy benefit with state-of-the-art HE designs in the automotive industry for exhaust gas-to-oil and exhaust gas-to-coolant heat transfer. Both physical testing and virtual simulation helped us develop a method to take advantage of the exhaust gas heat. The test result indicates that with the integration of the exhaust gas-to-coolant and exhaust gas-to-oil HEs, the gasoline engine makes a 0.5% and 0.8% fuel efficiency improvement, respectively. More specifically, the Worldwide harmonized Light vehicles Test Cycles (WLTC) fuel consumption on the 1.0L engine can be reduced by 0.5% with the integration of exhaust gas to the coolant HE, which has a smart bypass control strategy upstream of the oil cooler. Also the implementation of exhaust gas-to-oil HEs leads to a WLTC fuel consumption reduction of 0.8%. HE design with bypass valve and valve-controlled oil cooler from the experiments proved to be the most efficient HE design among the four investigated designs. The proposed simulation-based performance and engine dynamometer (dyno) evaluation shed light on the importance of selecting bypass valve and valve-controlled oil cooler HEs and design-related improvements in fuel economy for practical applications in building intelligent thermal management for vehicles.

History

Received: 31 Aug 2021
Revised: 30 Nov 2021
Accepted: 24 Jan 2022
e-Available: 08 Feb 2022

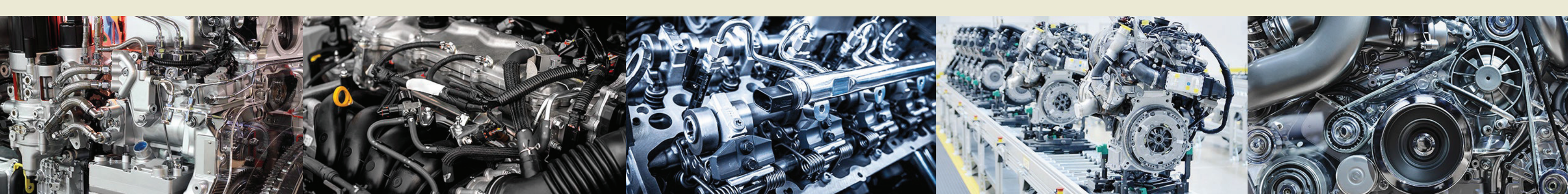
Keywords

Waste heat, Thermal efficiency, Heat transfer, Fuel economy

Citation

Kumar, V., Dadam, S., Zhu, D., and Mehring, J., "Fuel-Economy Performance Analysis with Exhaust Heat Recovery System on Gasoline Engine," *SAE Int. J. Engines* 15(6):2022, doi:10.4271/03-15-06-0045.

ISSN: 1946-3936
e-ISSN: 1946-3944



impact of the failed controlled valve due to stuck behavior and the hardware durability of HEs as the heat recovery system ages are not considered as part of our fuel economy estimate. Based on the above test results, it can be concluded that the best integration of the most efficient exhaust gas-to-coolant HE from HE2 leads to a WLTC fuel economy benefit of 0.5% applying a smart bypass control strategy. The exhaust gas-to-oil HE from HE1 OIL improves the WLTC fuel consumption by 0.8% if oil temperatures up to 130°C is tolerated and the oil-cooler is deactivated. All values have been determined for a Fox GTDI engine in combination with a B6 manual transmission.

6. Summary/Conclusions

As part of this project, the performance of several exhaust gas HEs has been investigated and optimized on a steady-state engine dyno. Detailed heat transfer maps have been determined and compared against each other for performance. To evaluate the benefits of these exhaust heat recovery technologies and to determine the ideal control strategy and integration into the cooling/lubrication system, a new numerical method has been developed and applied. This study presents the fundamental findings acquired from the experimental and numerical investigation of HEs. The key findings are summarized as follows:

1. It can be concluded that the WLTC fuel consumption of the Fox engine can be reduced by 0.5% by the integration of exhaust gas-to-coolant HE with a smart bypass control strategy upstream of the oil-cooler.
2. The implementation of exhaust gas-to-oil HE upstream of the main oil gallery leads to a WLTC fuel consumption reduction of 0.8%. The benefits will be even higher if the investigated exhaust heat recovery systems are combined with electrified or conventional powertrains without sophisticated thermal management technologies.
3. Among all the discussed exhaust gas-to-coolant HE designs, HE2 with bypass valve and valve-controlled oil cooler from the experiments proved to be an efficient HE design in terms of heating the coolant at a faster rate. The exhaust gas-to-oil HE from HE1 OIL improves the WLTC fuel consumption by 0.8% if oil temperatures up to 130°C are tolerated and the oil-cooler is deactivated.

This article reviews opportunities to improve the cost-benefit ratio; however, other aspects like quality, package, and cabin heating performance will be investigated in future research.

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Definitions/Abbreviations

BMEP - brake mean effective pressure
BSFC - brake-specific fuel consumption
CVSP - corporate vehicle simulation program
FC - fuel consumption
FMEP - friction mean effective pressure
GHG - greenhouse gas emissions
GT - GT-Suite model simulation
GTDI - gasoline turbocharged direct injection
HC - hot-cold factor
HE - heat exchanger
HE1 - heat exchanger from supplier 1
HE2 - heat exchanger from supplier 2
HE3 - heat exchanger from supplier 3
HDV - heavy-duty vehicles
HX - heat exchanger
ICE - internal combustion engines
NEDC - New European Driving Cycle
PH - powertrain hybridization
OFCA - oil filter cooler adapter
OHEX - oil heat exchanger
ORC - organic Rankine cycle
RRc - rolling resistance coefficient
WHR - waste heat recovery
WLTC - Worldwide harmonized Light vehicles Test Cycles

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