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A Novel Integrated Series Hybrid Electric Vehicle Model Reveals Possibilities for Reducing Fuel Consumption and Improving Exhaust Gas Purification Performance

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Abstract

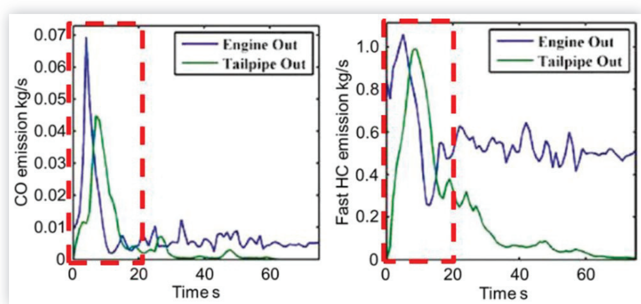
This paper describes the development of an integrated simulation model for evaluating the effects of electrically heating the three-way catalyst (TWC) in a series hybrid electric vehicle (s-HEV) on fuel economy and exhaust gas purification performance. Engine and TWC models were developed in GT-Power to predict exhaust emissions during transient operation. These models were validated against data from vehicle tests using a chassis dynamometer and integrated into an s-HEV model built in MATLAB/Simulink. The s-HEV model accurately reproduced the performance characteristics of the vehicle's engine, motor, generator, and battery during WLTC mode operation. It can thus be used to predict the fuel consumption, emissions, and performance of individual powertrain components. The engine combustion characteristics were reproduced with reasonable accuracy for the first 50 combustion cycles, representing the cold-start condition of the driving mode. Analysis of the TWC performance using the model showed that early activation of catalyst heating during the cold-start significantly improved exhaust gas purification performance but also increased vehicle fuel consumption by 2.66% over the entire driving cycle. However, the fuel consumption penalty could be reduced to 1.1 % without increasing emissions by modifying the engine's cold-start control strategy.

Introduction

Fuel economy standards and emission regulations for vehicles are becoming increasingly strict to combat global warming and air pollution. Consequently, there is an urgent need to improve fuel economy while reducing emissions. To comply with emissions standards, vehicles with gasoline engines use three-way catalysts (TWC) to remove over 99% of engine-out carbon monoxide (CO), nitrogen oxide (NOx), and hydrocarbon (HC) emissions from the exhaust. The three-way catalyst (TWC) is exposed to the exhaust gas, which is most efficient at high temperatures. Consequently, it performs poorly under low-temperature conditions such as cold starts, as shown in Figure 1. It is therefore important to find ways of increasing the temperature and activation points of TWCs.

HEVs can offer better fuel efficiency than conventional vehicles and are becoming increasingly popular because of the need to comply with stringent fuel efficiency and emission standards [2, 3, 4, 5, 6]; they are expected to account for approximately 50% of the passenger car market share by 2050, as shown in Figure 2. In practical gasoline s-HEVs, the engine is only used to charge the battery so that it can be operated at high efficiency at all time. This has a significant beneficial impact on fuel economy. However, the state of charge (SOC) of the traction battery may necessitate frequent stop-start operation of the internal combustion engine [2], which reduces

FIGURE 1 Typical CO and HC emissions profiles during a cold start in a gasoline engine [1].



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Definitions/Abbreviations

c_{CO2} - CO_2 concentration [mol/m^3]

c_{CO} - CO concentration [mol/m^3]

c_{HC} - HC concentration [mol/m^3]

α - H/C ratio

r_{EGR} - EGR rate

m_{in0} - Intake air mass (without EGR) [g/s]

m_0 - Intake air mass (with EGR) [g/s]

BM - Burned fuel fraction at Anchor Angle, 0.5 (50%)

BS - Burned fuel fraction at duration start, 0.1 (10%)

BE - Burned fuel fraction at Anchor duration end, 0.9 (90%)

D - Duration [crank angle deg.]

E - Wiebe Exponent

AA - Anchor angle [crank angle deg.]

f_{CE} - Fraction of fuel burned

BMC - Burned midpoint constant

BSC - Burned start constant

BEC - Burned end constant

WC - Wiebe constant

SOC - Start of combustion (engine) [crank angle deg.]/ State of charge (battery) [%]

m_u - unburned zone mass [kg]

m_f - fuel mass [kg]

m_a - air mass [kg]

$m_{f,i}$ - injected fuel mass [kg]

e_u - unburned zone internal energy [kJ]

V_u - unburned zone volume [m^3]

Q_u - unburned zone heat transfer rate [W/(m^{2}K)]