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Analysis of real driving gaseous emissions from light-duty diesel vehicles

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ABSTRACT

Increasingly strict emissions standards are providing a major impetus to vehicle manufactures for developing advanced powertrain and after-treatment systems that can significantly reduce real driving emissions. The knowledge of the gaseous emissions from diesel engines under steady-state operation and under transient operation provides substantial information to analyze real driving emissions of diesel vehicles. While there are noteworthy advances in the assessment of road vehicle emissions from real driving and laboratory measurements, detailed information on real driving gaseous emissions are required in order to predict effectively the real-time gaseous emissions from a diesel vehicle under realistic driving conditions. In this work, experiments were performed to characterize the behavior of NOx, unburned HC, CO, and CO_2 emitted from light-duty diesel vehicles that comply with Euro 6 emissions standards. The driving route fully reflected various real-world driving conditions such as urban, rural, and highway. The real-time emission measurements were conducted with a Portable Emissions Measurement System (PEMS) including a Global Positioning System (GPS). To investigate the gaseous emission characteristics, authors determined the road load coefficients of vehicle specific power (VSP) and regression coefficient between fuel use rate and VSP. Furthermore, this work revealed the correlation between the rates of average fuel use and each gaseous emission.

1. Introduction

Increasingly strict emissions standards are providing a major impetus to vehicle manufactures for developing advanced powertrain and after-treatment systems that can significantly reduce real driving emissions. In particular, innovative after-treatment systems have been developed to remove diesel exhaust emissions in a majority of diesel vehicle classes, and a number of emission reduction technologies require significant improvement in their performance. Gaseous emissions from a diesel engine typically depend on engine speed and load, consequently, the emissions measured from a vehicle operating under different conditions reveals significant differences in the quantity and chemical components of emissions. While there are noteworthy advances in the assessment of road vehicle emissions from real driving and laboratory measurements, detailed information on real driving gaseous emissions are required in order to predict effectively the real-time gaseous emissions from a diesel vehicle under realistic driving conditions.

It is generally known that real driving emissions are dependent on many parameters, such as vehicle characteristics and emission control technology, operation conditions, and fuel specification. In particular, NOx, unburned hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) are mainly responsible of severe environmental and health problems (Prasad and Bella, 2010). NOx emissions are usually formed in the region of high combustion temperatures and high oxygen concentration (Bosch, 2005; Lee et al.,

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2013), while hydrocarbons (Levsen, 1988) such as aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and aldehydes are produced due to incomplete combustion and unburned diesel fuels (Durán et al., 2002) or lubricating oils (Farrauto and Voss, 1996; Durán et al., 2002). CO formation is highest in rich mixtures where the excess-air factor is less than 1.0 (Wu et al., 2004), and is typically produced where the large droplets form or insufficient turbulence or swirl occurs in a diesel engine (International Energy Agency, 2017). For ideal thermodynamic equilibrium, the complete combustion of diesel fuel would only form CO_2 and H_2O in an engine (Prasad and Bella, 2010). CO_2 is the main reason for global warming, and transport is the second-largest sector in producing global CO_2 emissions with a range of 22% (Spreen et al., 2016). To eliminate gaseous polluting emissions such as NOx, unburned HCs, and CO is only possible with after-treatment systems. Among the emission control systems, most researchers focused on the development of advanced technologies for reduction of NOx emissions due to the highest percentage among the polluting emissions, such as exhaust gas recirculation (EGR), lean NOx trap (LNT), and Selective Catalytic Reduction (SCR). Furthermore, diesel oxidation catalyst (DOC) where HC and CO are oxidized and diesel particulate filter (DPF) systems where particulate matter (PM) emissions trapped are oxidized have been developed in a majority of diesel vehicle classes. For reducing CO_2 emission, significant improvements are needed in vehicle and fuel technology, such as hybrid technology, anti-idling, enhancement of energy efficiency, alternative fuels, and so on.

An important observation reported in previous studies (Boulter et al., 2007; Zhang et al., 2014; Myung et al., 2017; Galllus et al., 2017) was that the gaseous emissions are strongly associated with speed and load of engine operation, in a consequent, the gaseous emissions from a vehicle under real driving road conditions display significant differences in emission quantity and chemical components. Because of these complexities in the characteristic of diesel exhaust gas with respect to the operation conditions of vehicle, researchers typically analyze the emission data measured under the well-controlled conditions in laboratories, which is performed on a chassis dynamometer for measuring various emissions from a vehicle driving over a transient cycle representing the dynamic conditions of vehicle operation (Yamada et al., 2016).

However, such measurement provides inaccurate data for predicting the real driving gaseous emissions from vehicles, and the discrepancies can be attributed to several factors (Fu et al., 2013; Fontaras et al., 2014; Jaikumar et al., 2017) such as traffic, ambient conditions, driving patterns, driver's behaviors, and route severities. In particular, it has been demonstrated that real driving emissions exceed the levels attained in the laboratory-based type approval processes studies (Pathak et al., 2016).

To this end, the real driving emissions (RDE) test procedure will be introduced in 2017. This enables to control the levels of real driving emissions from vehicles with portable emissions measurement system (PEMS) studies (Kousoulidou et al., 2013). The technical verification for this methodology is performed by the European Commission, Bonnel et al. have revealed that the RDE test procedure would be useful to verify the in-service conformity and the durability of emission control devices of heavy-duty vehicles studies (Bonnel and Kubelt, 2011). Therefore, it is necessary to investigate the effect of real driving on the polluting emissions and greenhouse gas.

This study is motivated by the consideration of developing optimum real driving emission assessment methodology for light duty diesel vehicles. The present study aims to address the fuel-based gaseous emission characteristics and examine the road load coefficients of vehicle specific power (VSP) and regression coefficient between fuel use rate and VSP. Because the emission data analyzed in this work were directly collected from vehicles under the real driving conditions, our experiments are expected to provide more accurate results in subsequently predicting the amount of second-by-second gaseous emissions from diesel vehicles. The real-time emission measurements were conducted with a PEMS including a Global Positioning System (GPS).

2. Experimental methodology

The real driving gaseous emissions measurement was conducted on four light-duty diesel vehicles that comply with Euro 6b emissions standards. The vehicles used in this study were all new sedans with different engine volumes and average fuel economies. For controlling emissions, DPF and LNT were applied to all vehicles. Table 1 shows details for each vehicle that was used in this study, including model year, vehicle type, engine displacement and the number of cylinders, the after-treatment system for emission control, and fuel economy (Transportation Pollution Research Center, 2018).

The route for real-world driving reflected various driving conditions such as urban, rural, and highway. The distribution of velocities is summarized in Table 2. The road type for measuring emissions need to satisfy the requirements for minimum driving distance, driving distance share, average vehicle speed, and total driving time. With operation mode binning methodology applied to MOVES, three different driving conditions are defined. Since driving pattern on the urban road may include low average velocities due to congestion, average velocities below 40 km/h are categorized as urban driving. The velocity range of 40 and 80 km/h can be classified as rural driving, which is associated with rural road conditions such as sharp bends, speed limit zones, and free-flow. Lastly,

Table 1
Vehicle specifications and fuel economy.

Vehicle	Model year	Vehicle type	Engine displacement	Engine cylinders	Emission control system	Fuel economy (km/L)
#1	2015	Sedan	1.6	4	DPF, LNT	20.6
#2	2015	Sedan	2.0	4	DPF, LNT	18.4
#3	2015	Sedan	2.0	4	DPF, LNT	19.5
#4	2015	Sedan	2.0	4	DPF, LNT	20.1