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Characteristics of on-road NO_x emissions from Euro 6 light-duty diesel vehicles using a portable emissions measurement system

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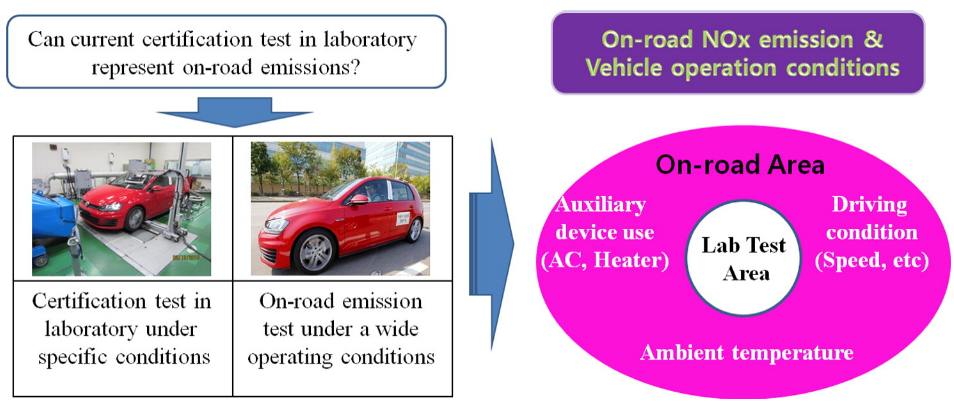
HIGHLIGHTS

- On-road NO_x emissions from Euro 6 diesel vehicles were examined using a PEMS.
- Total NO_x emissions in route 1 were higher by −4-60% than those in route 2.
- NO_x emissions when the AC was used were higher by 68% and 85% for routes 1 and 2.
- Moving averaging window showed higher NO_x emissions by 2–31% than power binning method.
- Lower ambient temperatures showed higher NO_x emissions by 82–192%.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the on-road nitrogen oxides (NO_x) emissions measurements from Euro 6 light-duty diesel vehicles using a portable emissions measurement system on the predesigned test routes in the metropolitan area of Seoul, Korea. Six diesel vehicles were tested and the NO_x emissions results were analyzed according to the driving routes, driving conditions, data analysis methods, and ambient temperatures. Total NO_x emissions for route 1, which has higher driving severity than route 2, differed by −4-60% from those for route 2. The NO_x emissions when the air conditioner (AC) was used were higher by 68% and 85%, on average, for routes 1 and 2, respectively, compared to when the AC was not used. The analytical results for NO_x emissions by the moving averaging window method were higher by 2–31% compared to the power binning method. NO_x emissions at lower ambient temperatures (0–5 °C) were higher by 82–192% compared to those at higher ambient temperatures (15–20 °C). This result shows that performance improvements of exhaust gas recirculation and the NO_x after-treatment system will be needed at lower ambient temperatures.

Abbreviations: BC, black carbon; CARS, competitive automotive regulatory system; CNG, compressed natural gas; CO, carbon monoxide; CO_2, carbon dioxide; CVS, constant volume sampler; DPF, diesel particulate filter; EC-JRC, European Commission-Joint Research Center; EGR, exhaust gas recirculation; HC, hydrocarbon; GPS, global positioning system; LDDV, light-duty diesel vehicle; MAW, moving averaging window; NEDC, new European driving cycle; NIER, National Institute of Environmental Research; NO_x, nitrogen oxides; NTE, not-to-exceed; PEMS, portable emissions measurement system; PM, particulate matter; RDE-LDV, real-driving emissions - light-duty vehicle; RPA, relative positive acceleration; SO_2, sulfur dioxide; VOC, volatile organic compound.

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1. Introduction

Nitrogen oxides (NO_x) act as precursors in the photochemical formation of tropospheric ozone (Yao et al., 2015) and contribute to the secondary formation of fine particles less than 2.5 μm in size ($PM_{2.5}$) (Tan et al., 2009). Lower size particles that newer diesel vehicles emit higher amount than older vehicles are more harmful than larger size particles to human health because of large surface area (Golokhvast et al., 2015). Power plants and road transportation are the major sources of NO_x emissions (Yao et al., 2015). In Korea, road transport contributes more than 30% of the total national NO_x emissions, and approximately 85% of NO_x emissions from mobile sources are derived from diesel vehicles (Li et al., 2013). Although the Korean government implemented the Euro 5 and Euro 6 emissions standards for new vehicles in 2009 and 2014, respectively, to mitigate NO_x emissions from diesel vehicles, nitrogen dioxide (NO_2) concentrations in metropolitan areas such as Seoul still did not show a decreasing trend (Seoul Metropolitan Government, 2015).

Two methods exist to characterize the exhaust emissions from vehicles: (1) laboratory tests using a chassis dynamometer, and (2) on-road tests using a portable emissions measurement system (PEMS). The recent development of PEMSs enables researchers to measure the emissions characteristics of vehicles under real-world driving conditions (Wang et al., 2014). Accordingly, numerous emissions measurement studies from diesel vehicles have been conducted using PEMS (Wang et al., 2012; Yao et al., 2015; Liu et al., 2011; Fu et al., 2013; Chen et al., 2007; Cao et al., 2016; Mamakos et al., 2013; Rubino et al., 2009). In addition, various studies have been performed that extensively measured exhaust emissions, in particular, volatile organic compounds (VOCs) (Ait-Helal et al., 2015; Cao et al., 2016), carbonyls (Nogueira et al., 2015), particulate matter (PM) (Li et al., 2013; Mamakos et al., 2013; Merkisz et al., 2011), and NO_x (Weiss et al., 2012; Yao et al., 2015; Fu et al., 2013; Lee et al., 2013).

On-road emissions studies were conducted using various types of vehicles such as heavy-duty diesel vehicles (Durbin et al., 2008), liquefied petroleum gas taxis (Lau et al., 2011), gasoline- and diesel-fueled vehicles (Huang et al., 2013), diesel and compressed natural gas (CNG) waste collection trucks (Fontaras et al., 2012), and construction equipment (Fu et al., 2012). On-road emissions and fuel consumption levels have also been investigated using PEMS (Rubino et al., 2009; Wang et al., 2011a, b) and on-road vehicle emissions factors were estimated for various pollutants: carbon monoxide (CO) and NO_x (Deng et al., 2015); NO_x and black carbon (BC) (Wang et al., 2012); and CO, BC, and PM (Wang et al., 2011a, b). Qu et al. (2015) analyzed vehicle emissions according to driving conditions using a PEMS; Fuo et al. (2012) generated CO, hydrocarbon (HC), and NO_x emissions factors using 57 light-duty gasoline vehicles, covering Euro 0-Euro 4 technologies; and Liu et al. (2009) also obtained CO, HC, NO_x, and PM emissions factors for Euro 0-Euro 3 trucks for various driving routes. The COPERT emissions factors were used to estimate the air pollutant emissions from on-road vehicles in China (Lang et al., 2014) and the emissions factors for CO_2, total hydrocarbon, CO, and NO_x measured on the road were compared to their corresponding COPERT emissions factors (Kousoulidou et al., 2013). Goel and Guttikunda (2015) evaluated the on-road vehicle emissions over 40 years (1990–2030) in Delhi, India and showed that NO_x and CO_2 emissions increased, while the emissions of PM, sulfur dioxide (SO_2), CO, and VOCs decreased. Johnson et al. (2009) made on-road comparisons between a mobile emissions laboratory and a PEMS for different conditions in the not-to-exceed (NTE) engine-operating zone to explore error differences. They reported that the PEMS brake-specific NO_x NTE emissions were biased high relative to the mobile emissions laboratory. Weiss et al. (2011) studied the on-road emissions of 12 light-duty diesel and gasoline vehicles extensively using a PEMS and concluded that on-road NO_x emissions of light-duty diesel vehicles (LDDV) differ substantially between laboratory new European driving cycle (NEDC) testing and actual on-road driving.

The committee of the competitive automotive regulatory system (CARS21) in Europe pointed out high NO_x concentrations in many big cities and suggested that measures to reduce on-road NO_x emissions from diesel vehicles be prepared (CARS21, 2012). Based on this proposal, the European Commission-Joint Research Center (EC-JRC) started to develop the Real-Driving Emissions - Light-duty Vehicles (RDE-LDV) program and announced they would establish the test method and standard by 2015 for execution of this program starting in September 2017 (EC-JRC, 2013). High levels of on-road NO_x emissions were reported from the EC-JRC study. The center conducted on-road tests of NO_x emissions with a PEMS for 12 diesel vehicles from 2007 to 2010 and the concentrations were 4–7 times higher than certification levels were (Weiss et al., 2011).

This study was conducted to evaluate on-road NO_x emissions from Euro 6 diesel vehicles manufactured in Korea. To achieve this goal, on-road NO_x emissions from six LDDVs with lean NO_x trap systems were tested using a PEMS. Two driving routes, which satisfy the European on-road driving standard, were selected, and emissions were measured and compared by driving route, driving conditions, data analysis method, and ambient temperature. The results of this study will be useful in understanding the characteristics of real NO_x emissions from Euro 6 LDDVs in Korea.

2. Experimental

2.1. Test vehicles and driving routes

On-road emissions tests were conducted using six diesel vehicles that comply with Euro 6 emissions standards. One vehicle was an SUV and the other five were sedans. All test vehicles were new LDDVs with engine volumes that ranged from 1.6 to 2.2 L. The specifications of the test vehicles are listed in Table 1.

The test driving routes were designed to reflect the characteristics of a Korean on-road driving test. To accomplish this, two driving routes that satisfied the RDE-LDV standards were selected, considering the severity of the driving conditions. Each test route reflected the diversity of normal on-road driving as much as possible and included a mix of urban, rural, and motorway driving. The driving routes for the PEMS test are described as follows and mapped out in Fig. 1.

Route 1: Haengsin Station – Dokribmun – Gupabal – Jangheung – Euijungbu – Howon I/C (outside motorway) – Goyang I/C.

Route 2: Neunggok Station – Geongbok Palace – Sogang great bridge – Gimpo great bridge – Haengsin Station – Incheon airport motorway – Geumsan I/C.

The relative positive acceleration (RPA) was calculated as a function of average vehicle speed by analyzing the data obtained from each driving route's test (Fig. 2). RPA shows how a driving route has various driving conditions. Both driving routes presented wider RPA-speed distribution compared to the certified testing mode, thus NO_x emissions were likely to be higher due to higher acceleration ranges. Route 1 showed higher driving severity compared to route 2, due to high relative positive acceleration in the mid- and high-speed ranges and higher-altitude roads in the rural and motorway sections as shown in Fig. 3. The core of this new testing method is that the vehicles should meet the standard, also called the conformity factor for all routes, even if they have different driving severities.

2.2. Measurement system

A PEMS manufactured by Horiba (Horiba OBS-2200, Kyoto) was installed in the cabins of the tested vehicles, and measurements were carried out according to the test method described by the RDE-LDV program. A Horiba OBS-2200 system consists of an exhaust gas flow meter, an exhaust gas-sampling device, a gas analyzer, a power supplying system, a control system, and a data analysis system. Real-time exhaust concentration (g/s) data were coupled with exhaust mass flow rates