Transportation Research Part D 53 (2017) 428–439

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Fine particle emission characteristics of a light-duty diesel vehicle according to vehicle acceleration and road grade

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ARTICLE INFO

Article history:

Keywords:
Diesel vehicle emission
Particle number
Particle mass
Vehicle acceleration
Road grade

ABSTRACT

The characteristics of fine particle emission from a light-duty diesel vehicle operated on a chassis dynamometer were investigated according to vehicle acceleration and road grade. Particle number (PN) concentration and particle mass (PM) concentration were measured using a Solid Particle Counting System (SPCS), an Engine Exhaust Particle Sizer (EEPS), and a Dekati Low Pressure Impactor (DLPI). In this study, actual mass distribution of particles emitted from the tested diesel vehicle was determined by sampling the particles on 25-mm Teflon-coated filters installed at 13 impactor stages of the DLPI and then compared with the particle mass distribution converted from the particle number distribution measured by the EEPS. In order to evaluate the characteristics of fine particle emission under various conditions of vehicle acceleration and road grade, testing was conducted with or without installing a Diesel Particulate Filter (DPF). In general, PN and PM concentrations increased with both increasing vehicle acceleration and increasing road grade.

1. Introduction

The proportion of the sources of road pollution to the sources of air pollution is increasing with increasing number of vehicles. Therefore, substantial efforts have been made to reduce exhaust gas emissions from vehicles, and, as part of these efforts, vehicle emission standards are getting tighter. Meanwhile, diesel engines generally emit less CO_2 than gasoline engines, and have merits of great torque and high thermal efficiency. However, the diesel engines have a disadvantage that they emit relatively large amount of NO_x and particulate matter which can cause respiratory disease (Myung and Park, 2012). Currently, many nations in East Asia, North America, and Europe regulate fine particle emissions from diesel vehicles by particle mass (PM). In particular, the European Union (EU) has regulated the fine particle emissions from diesel vehicles not only by PM but also by particle number (PN) since the enactment of EURO 5b standard. Thus, the necessity to control the fine particle emission from diesel vehicles is raised, and there are requirements in place to equip diesel vehicles with the reduction systems such as diesel particulate filters (DPF), diesel oxidation catalysts (DOCs), and exhaust gas recirculation (EGR).

Accordingly, substantial studies have been conducted to investigate number concentration and/or mass concentration of particles emitted from diesel vehicles as relating to the reduction systems in place. In addition, studies on the properties of fine particles emitted from diesel engines as relating to engine control and mixed air conditions have been performed. van

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http://dx.doi.org/10.1016/j.trd.2017.04.041
1361-9209/

Gulijk et al. (2001) analyzed fine particle properties generated from diesel engines using an Electrical Low-Pressure Impactor (ELPI), which measures number and mass concentrations. Biswas et al. (2008) studied the influence of various post processing systems in relation to fuels and driving conditions, based on the chassis dynamometers of diesel engines of different years. They used a Nano-MOUDI impactor and an Engine Exhaust Particle Sizer (EEPS) to compare size distribution, mass emission factor, and surface equivalent diameter of particles emitted from late model heavy-duty diesel vehicles, depending on driving cycles. Nabi et al. (2012) measured the number concentration of fine particles in relation to engine torque by using diesel and marine gas oil (MGO) as fuel, and estimated the mass concentration of fine particles. They compared number concentrations measured by an ELPI and a Scanning Mobility Particle Sizer (SMPS), and analyzed the effect of engine torque on total particulate matter determined by gravimetric measurement. Ushakov et al. (2013) studied the influences of engine load, power, and speed on particle emission from a diesel engine in relation to mixed air temperature. They compared number distributions measured by an ELPI and an SMPS, and analyzed mass concentrations obtained from the ELPI measurement data. Quiros et al. (2014) evaluated the quantity of fine particles emitted from a diesel engine with the use of a DPF under controlled conditions without engine load. They analyzed particulate mass emission by measuring particles using instruments like DustTrak, EEPS, SMPS, and Dekati Mass Monitor (DMM), and compared the results with those obtained by gravimetric method. Maricq et al. (2006) analyzed sub-micron aerosol mass emissions from conventional diesel and gasoline direct injection (GDI) vehicles by using an ELPI, and compared the results with those determined by filter-based gravimetric measurement. Quiros et al. (2015) estimated particulate matter mass emissions from GDI, port-fuel injected (PFI), and diesel vehicles by using instruments like Aerosol Particle Sizer (APS), EEPS, and SMPS, and compared the results with those obtained by gravimetric method. In addition, Chase et al. (2004), Zervas and Dorlhène (2006), Giechaskiel et al. (2008), Li et al. (2014), and Xue et al. (2015) used real-time aerosol detectors like APS, EEPS, ELPI, and SMPS to determine mass distribution of particles emitted from diesel or gasoline vehicles under various driving conditions or fuel types, and they compared the results with those obtained by gravimetric method. Furthermore, on-road emission from diesel vehicles has been investigated by using on-board measuring systems (Coelho et al., 2009; Jayaratne et al., 2009; López et al., 2009; Sonntag et al., 2013; Zhang et al., 2016).

Many studies on fine particle emissions from diesel vehicles have reported PN and/or PM results based on either emission test cycles such as federal test procedure (FTP-75) and new European driving cycle (NEDC), or general driving conditions including a constant speed mode. This means that driving conditions should also be considered in controlling fine particle emissions from diesel vehicles, in addition to reduction system, engine control, and mixed air condition. However, studies on either number concentration and/or mass concentration of fine particles emitted from diesel vehicles as relating to vehicle acceleration are still lacking. Moreover, most of the studies including the abovementioned studies characterized the mass concentration of fine particles emitted from diesel engines by using the instruments like DMM, DustTrak, EEPS, ELPI, and SMPS, *i.e.*, the instruments which basically measure the number distribution of particles, but not directly the mass distribution of particles. In other words, substantial studies have reported the converted mass distributions of particles emitted from diesel engines. The gravimetric method can be employed to measure actual mass concentrations, but it has some problems like low time-resolution, high value of minimum detection limit, and complexity in operation. However, due to the fact that there have not been enough studies evaluating the characteristics of fine particle emission by measuring actual particle mass distributions, the studies relating to actual mass distribution of particles emitted from diesel engines are worth being carried out. Fujitani et al. (2006) measured actual mass distribution of fine particles emitted from a diesel vehicle by collecting the particles using cascade impactors under driving conditions with one case of vehicle speed and one case of vehicle acceleration. However, these studies are not sufficient to understand the actual mass distribution of particles emitted from diesel vehicles as relating to actual driving conditions based on vehicle acceleration and road grade. In this study, actual mass distribution as well as number distribution of fine particles emitted from a diesel vehicle were evaluated under specific driving conditions with various vehicle accelerations and road grades.

2. Experimental

The experiments were conducted by using a vehicle equipped with a common rail diesel engine, and the specifications of the tested diesel vehicle are listed in Table 1. The experimental setup to measure fine particle emissions from the diesel vehicle was composed of a chassis dynamometer (ROADSIM 48″ MIM CAR, AVL Ltd., Graz, Austria), a constant volume sampler (CVS-ONE, Horiba Ltd., Kyoto, Japan), a solid particle counting system (MEXA-2000SPCS, Horiba Ltd., Kyoto, Japan), an Engine Exhaust Particle Sizer (EEPS 3090, TSI Ltd., Minnesota, USA), a Dekati low pressure impactor (DLPI, Dekati Ltd., Kangasala, Finland), and a PM holder, as shown in Fig. 1. For the PN measurement, the number concentration of particles emitted from the diesel vehicle was first diluted in the CVS tunnel, and then two particle number diluters, *i.e.*, PND1 and PND2, and a heated tube were used before the SPCS, based on the Particulate Measurement Programme (PMP) established under the

Table 1
Specification of the tested diesel vehicle.

Engine type	Displacement	Max. Power	Max. Torque	Weight
l4 2.5 VGT	2497 cc	175 hp/3800 rpm	46 kg m/2000 rpm	2280 kg