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A PEMS study of the emissions of gaseous pollutants and ultrafine particles from gasoline- and diesel-fueled vehicles

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HIGHLIGHTS

- We measured gasoline- and diesel-fueled vehicles by a PEMS system.
- The emission factors show strong relationship with real-world driving conditions.
- Gasoline- and diesel-fueled vehicles show special size distributions.
- Gasoline car emitted more nano-particles than diesel vehicles.
- Particles show growth trends with the increase of VSP and speed in real-world.

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ABSTRACT

On-road emission measurements of gasoline- and diesel-fueled vehicles were conducted by a portable emission measurement system (PEMS) in Shanghai, China. Horiba OBS 2200 and TSI EEPS 3090 were employed to detect gaseous and ultrafine particle emissions during the tests. The driving-based emission factors of gaseous pollutants and particle mass and number were obtained on various road types. The average NO_x emission factors of the diesel bus, diesel car, and gasoline car were 8.86, 0.68, and 0.17 g km^{-1}, all of which were in excess of their emission limits. The particle number emission factors were 7.06×10^{14}, 6.08×10^{14}, and 1.57×10^{14} km^{-1}, generally higher than the results for similar vehicle types reported in the previous studies. The size distributions of the particles emitted from the diesel vehicles were mainly concentrated in the accumulation mode, while those emitted from the gasoline car were mainly distributed in the nucleation mode. Both gaseous and particle emission rates exhibit significant correlations with the change in vehicle speed and power demand. The lowest emission rates for each vehicle type were produced during idling. The highest emission rates for each vehicle type were generally found in high-VSP bins. The particle number emission rates of the gasoline car show the strongest growth trend with increasing VSP and speed. The particle number emission for the gasoline car increased by 3 orders of magnitude from idling to the highest VSP and driving speed conditions. High engine power caused by aggressive driving or heavy loads is the main contributor to high emissions for these vehicles in real-world situations.

1. Introduction

The development of vehicles has aroused a heated debate due to their high exhaust emissions. Gaseous emissions from vehicles, including NO_x, VOCs, and CO, have been accepted as the primary precursors of photochemical smog. Ultrafine particles have attracted increasing attention due to their strong impact on aerosol formation (Finlayson-Pitts and Pitts, 1997; Zhang, 2010) and adverse health effects (Nel, 2005; Pope and Dockery, 2006). Diesel exhaust and its photo-oxidation have been proven to be a major source of carbonaceous aerosols in ambient air (Robinson et al., 2007; Weitkamp et al., 2007; Chirico et al., 2010). The latest monitoring studies further demonstrate that gasoline exhaust also contributes significantly to the secondary organic aerosols in the atmosphere (Gentner et al., 2012; Bahreini et al., 2012). Therefore, it is essential

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to clarify the emission characteristics of diesel and gasoline vehicles to determine their contributions to the fine particles in the atmosphere.

To better understand the emission characteristics of diesel and gasoline vehicles, many measurements have been conducted in recent years. The portable emission measurement system (PEMS) has been developed as an effective and practical method to quantify vehicle emission levels in real-world situations (Durbin et al., 2007; Zhang and Frey, 2008). Previous studies have conducted numerous tests to measure the exhaust emissions of different types of vehicles using PEMS, which revealed that vehicle emissions are strongly related with such factors as driving cycle, fuel quality, and after-treatment equipment (Durbin et al., 2008; Merkisz et al., 2009; Martini et al., 2009; Johnson et al., 2011). PEMS studies have also gradually been carried out in Chinese cities (Chen et al., 2007; Liu et al., 2009, 2011; Wu et al., 2012). These studies have produced many constructive results for in-use vehicle emission characteristics and have laid a solid foundation for policy-making regarding vehicle pollution control in China. However, ultrafine particle emissions from in-use vehicles under real-world driving conditions remain uncharacterized.

Vehicle exhaust has been proven to contain large quantities of ultrafine particles smaller than 0.1 μm. Taking diesel engines as an example, the particles in diesel exhaust are generally distributed in nucleation and accumulation modes (Kittelson, 1998). Particles in nucleation mode are usually smaller than 50 nm in diameter in the liquid state (Shi et al., 2000). Nucleation-mode particles tend to be formed by the nucleation of organic and sulfur compounds during dilution and cooling processes (Wong et al., 2003; Giechaskiel et al., 2005; Rönkkö et al., 2006). Sakurai et al. (2003) further reported the compositions of organic compounds and sulfur acid in the nanoparticles and indicated that the sulfur contents in fuel and lube oil play important roles in the formation of nanoparticles, which has been confirmed by other studies (Maricq et al., 2002; Du and Yu, 2006; Lähde et al., 2009). Accumulation-mode particles consist of solid carbonaceous agglomerates with adsorbed and condensed semi-volatile species.

To control the gaseous and particle emissions from vehicles, more stringent emission standards have gradually been implemented in most countries. China plans to enforce Euro 4 standards on heavy-duty diesel vehicles beginning in the middle of 2013. NO_x and particle emission limits will be further constrained. Several cities have been trying to implement Euro 5 standards for light-duty vehicles in recent years. Considering that there will be an extra limit on particle number emissions in the second stage of the Euro 5 standard, more attention has been paid to studying the particle emission characteristics and their impact factors. Several studies have reported that fuel quality and after-treatment devices play positive roles in reducing the vehicle emissions (Vaaraslahti et al., 2004; Bergmann et al., 2009; Lähde et al., 2010, 2011). To determine the real-world emission characteristics, especially for ultrafine particles of new types of gasoline and diesel vehicles, on-board vehicle emission measurements were carried out by PEMS in this study. Each vehicle type satisfies the latest emission standards in Shanghai, China. This study aimed to produce gaseous and ultrafine particle emission factors for the latest vehicle types and discuss the impacts of real-world driving conditions on emission characteristics.

2. Materials and methods

2.1. Tested vehicles

The on-road emission tests were conducted in 2011 in Shanghai, China. Several vehicle types were selected in this study, including a heavy-duty diesel bus (HDDB), a light-duty diesel car (LDDC), and a light-duty gasoline car (LDGC). The specifications of the test vehicles were listed in Table 1. Each vehicle type satisfies the latest emission standards in Shanghai. The gasoline and diesel fuel used in the test were obtained directly from the market. The fuel quality met the requirements of the local standard equivalent to Euro 4. The sulfur content of both gasoline and diesel fuel should be controlled below 50 ppm.

2.2. Test cycles

The driving route for on-board measurement was designed to simulate real traffic conditions in Shanghai. The bus testing route was mainly located in the urban area of Shanghai. The total distance of the route was approximately 22 km. Elevated roads, arterial roads, and residential roads comprised 26%, 38%, and 35% of the route by length, respectively. The testing route of light-duty cars covered all urban and suburban road types. The total distance of the route was approximately 90 km, consisting of elevated roads (20%), highways (25%), arterial roads (40%), and residential road (15%). Each tested vehicle was driven twice per day. Table 2 shows the driving condition parameters during the testing of each vehicle type. Because the bus testing route was mainly distributed in an urban area, the average speed of the bus on the testing route was only 60% of that of the light-duty cars. Additionally, the bus operation included more idling than that of the other two tested vehicles. The driving conditions of the light-duty diesel and gasoline cars were quite similar. In general, the test routes reflect the driving characteristics of buses and cars in Shanghai (Chen et al., 2007; Wang et al., 2008).

The test length of the light-duty diesel car is shorter because we deleted abnormal data recorded when the rotating disk of the particle measurement system was dysfunctional because of the vibration during the second half of the test.

2.3. Measurement system

A Horiba OBS 2200 PEMS was utilized for gaseous pollutants tests. The OBS system employs a non-dispersive infrared (NDIR) analyzer to measure CO and CO_2, a flame ionization detector (FID) analyzer to measure THC, a chemiluminescent detection (CLD) analyzer to measure NO and NO_2, and an electrochemical sensor to measure O_2. The carbon balance method was used to determine fuel consumption. The system was equipped with a 4-inch flow meter based on Pitot tube technology to measure instantaneous vehicle exhaust flow. The equipment also includes a barometer for measuring ambient humidity and temperature. Vehicle speed, altitude, latitude, and longitude were logged continuously by a GPS

Table 1
Test vehicle specifications.

Vehicle type	HDDB	LDDC	LDGC
Fuel type	Diesel	Diesel	Gasoline
Vehicle mass (t)	~28	~2.5	~1.5
Engine type	Common rail; turbocharged intercooler	Turbo direct injection	Normally aspirated
Displacement (L)	7.1	1.9	1.8
After treatments	Selective catalytic reduction (SCR)	Diesel oxidation catalyst (DOC)	Three-way catalytic converter (TWC)
Emission standard	Euro 4	Euro 3	Euro 4
Model year	2010	2010	2011
Mileage traveled (km)	53,550	21,390	32,454