*Aerosol and Air Quality Research*, 18: 1448–1456, 2018

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2017.11.0535

# The Real-world Emissions from Urban Freight Trucks in Beijing

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## ABSTRACT

The emissions from 7 urban freights were tested using a portable emission measurement system (PEMS) and analyzed based on the vehicle-specific power (VSP) method. The results show that both gaseous pollutants and PM emissions increase with VSP. With regard to CO and HC, emissions decrease with elevated speed and acceleration. The PM and $NO_x$ emitted from China IV vehicles are significantly less than those from China III vehicles, but emissions of CO and HC exhibit a different tendency, thus necessitating further research. In addition, speed and acceleration show a slight influence on $NO_x$ emissions. The VSP plays an important role in the emissions from urban freight trucks. Therefore, a comprehensive evaluation of the emission characteristics of these vehicles in megacities is needed in order to take effective measures.

***Keywords***: PEMS; VSP; Urban freight vehicles; Emission.

## INTRODUCTION

With the remarkable development of social economic and urbanization in the past years in China, the vehicle population (excluding rural vehicles) increased from 5.5 million in 1990 to 194 million in 2016 (NBSC, 2016; Wu *et al.*, 2017). In particular, the average annual growth rate has arrived at 16% in recent years (NBSC, 2015). Meanwhile, as one of the most important contributors to urban air pollution, vehicle emission has attracted considerable attention. As for Beijing, a largest metropolis placing strict standard on vehicle emissions in China, its vehicle ownership is approximately 250 per 1000 people, which is much higher than the national average (NBSC, 2015). Thus, the air quality in Beijing confronts severe challenge.

Hitherto, several approaches have been put forward to reduce the impact on urban air quality from vehicle emissions, which consist of improving transportation planning and traffic management, and implementation of more stringent emission standards (Yao *et al.*, 2015a; Wu *et al.*, 2017). With the implementation of these measures, although the air quality has been improved, several investigations have reported that there is no significant reduction in the emission factors of $NO_x$ in the on-road measurements by using portable emission measurement system (PEMS) (Huo *et al.*, 2012; Shen *et al.*, 2015; Yao *et al.*, 2015c; Zhang *et al.*, 2016a). Up to now, there have been numerous publications focused on emission measurement under the real-world driving conditions by using PEMS (Khan *et al.*, 2012; Fu *et al.*, 2013; Yang *et al.*, 2015; Yao *et al.*, 2015b; Liu *et al.*, 2017) and the available results provide the data support for vehicle pollution control.

In addition, several works have reported the diesel truck emissions with different approaches (Huo *et al.*, 2011; Tsai *et al.*, 2011; Huo *et al.*, 2012; Yao *et al.*, 2015c; Yang *et al.*, 2017). Yang *et al.* (2015) adopted the road emission intensity-based (REIB) approach to estimate the emissions of diesel freight trucks and established the province-based emission inventory. Zheng *et al.* (2015) obtained the black carbon emissions from twenty-five heavy-duty diesel vehicles by using PEMS. Yao *et al.* (2015a) investigated the on-road emissions characteristics of nine heavy-diesel trucks in Xiamen. Furthermore, in order to investigate urban diesel vehicle emissions, many works were focused on bus emissions. Yu *et al.* (2016) pointed out that the diesel bus emissions and fuel consumption based on the real-world test were related to vehicle's speed and acceleration. López-Martínez (2017) estimated the emissions of urban bus fleets in Madrid using an integrated methodology. Our

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previous work studied the bus emissions and found that nanometer size particle played a key role in PN (Liu *et al.*, 2011).

Based on the aforementioned review, it is shown that the investigations on the urban freight truck emissions are still scarce, especially in megacity. Although Zhang *et al.* (2016b) reported that the characteristics of gaseous and particulate pollutants from three logistics transportation diesel vehicles in Chengdu China, the emissions of Beijing are different from Chengdu due to the differences in road conditions, traffic management, the ownership of vehicles and the freight transportation. In addition, freight trucks for supermarket and logistic companies are not limited by tail number requirements in Beijing. Such kinds of trucks can travel from Monday to Sunday inside the fifth ring. The emissions of urban freight trucks have made huge contributions to the total vehicle emissions. Thus, on-road emissions of seven urban freight trucks were measured with PEMS in Beijing in this work. The influence of vehicle specific power (VSP) on gaseous pollutants and PM was addressed. The relevant conclusions will not only be helpful for understanding the real world emission of urban freight trucks in Beijing, but also provide reference for the other provinces in China and enrich the emission data.

## MATERIALS AND METHODS

### *Tested Trucks and Routes*

The on-road emission tests were conducted in 2016 in Beijing. Seven vehicles in different types were selected in the tests, including four diesel trucks of the China III emission standard and three light-duty diesel trucks of the China IV emission standard. The specifications of the tested vehicles are listed in Table 1. Each vehicle meets the latest local emission standards. The sulfur contents of fuel obtained from the local retail petrol stations in the tests are in accordance with Chinese standard GB17040-2008.

The test routes were nearly the daily routes of these vehicles. The test area was in the northwest of Beijing city, which covered from the third ring road to the fifth ring road. Transportation environment simulated the actual situations of tested vehicles they faced every day. According to the local traffic bans, trucks should not be driven at 07:00–09:00 and 16:00–20:00.

### *Measurement Systems*

As shown in Fig. 1, in order to collect the data about instantaneous exhaust emissions and driving pattern on the road, PEMS was employed to measure the emissions from freight trucks. PEMS consisted of two sections: SEMTECH-DS (Sensors Inc., U.S.) and Pegasor particle sensors MI2 (PPS-M, Pegasor Inc., Finland). The SEMTECH-DS was used to measure gaseous pollutants. In this device, CO and $CO_2$ concentrations were measured by non-dispersive infrared (NDIR); total hydrocarbon (THC) was measured by flame ionization detector (FID); $NO_x$ was determined by non-dispersive infrared (NDIR). Connected with the Semtech-DS, the weather station was used to detect ambient temperature, humidity and pressure. The Global Positioning System (GPS) was used to obtain the speed, acceleration and road grade information, which was indispensable for subsequent VSP calculation. Vehicle exhaust flow rate and temperature were determined by exhaust flow meter (EFM), which was installed in the upstream of the exhaust port.

**Table 1.** Specifications of the tested freight tucks.

| Test no. | Fuel Type | Emission Standard | Total Mass (kg) | Date of Production | Power (kW) |
|---|---|---|---|---|---|
| 1 | Diesel | China III | 8495 | 2010.6.10 | 115 |
| 2 | Diesel | China III | 8490 | 2010.4.19 | 103 |
| 3 | Diesel | China III | 8010 | 2009.2.23 | 96 |
| 4 | Diesel | China III | 8495 | 2012.9.6 | 115 |
| 5 | Diesel | China IV | 7700 | 2011.10.20 | 100 |
| 6 | Diesel | China IV | 4390 | 2013.9.24 | 95 |
| 7 | Diesel | China IV | 4490 | 2015.6.19 | 87 |

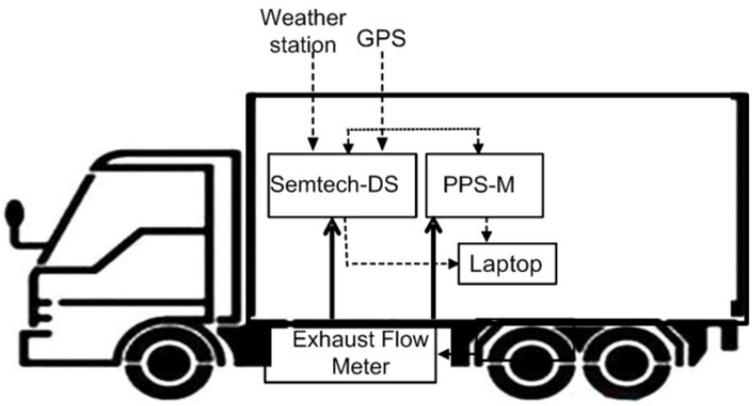


**Fig. 1.** Schematic diagram of test system.

The PPS-M was used to record the instantaneous particulate matter emission data. This instrument was based on particle charging and electrical detection of charged particles. The PPS-M was capable of measuring airborne particle size distribution ranging from 23 nm to 2.5 µm. The laptop was adopted to collect second by second data and control all the instruments.

It is worth noting that the equipment needed to be warmed up for at least one hour before the measurement. After the warm-up, it was necessary to examine the air leakage of the exhaust pipes and other flow devices. To ensure the accuracy of data, the Semtech-DS must be zeroed and calibrated prior to each separate test (Fu *et al.*, 2012; Peng *et al.*, 2016). Besides, fuel consumption was calculated with carbon balance method on the basis of $CO_2$, CO and THC emission data.

### *Calculation of VSP*

As for the data analysis, emission factors were easily influenced by factors, such as engine load. In this work, $CO_2$-based emissions and VSP were selected to analyze. The VSP is highly correlated with vehicle emission. It is defined as the engine power output per vehicle unit mass, which is a practical indicator of real-world driving emissions (Frey *et al.*, 2010) and is expressed as a function of vehicle speed, road grade and acceleration. It could be expressed as Eq. (1):

$$VSP = v(\mathrm{a} + \mathrm{g}\sin\theta + \mathrm{g}C_R) + \frac{1}{2}\rho_a \frac{C_D A}{m} v^3 \quad (1)$$

where VSP is vehicle specific power (kW $kg^{-1}$); $v$ is the vehicle speed (m $s^{-1}$); g is the gravitational acceleration, 9.807 m $s^{-2}$; $\theta$ is the road grade, 0; $a$ is the vehicle acceleration, (m $s^2$); $C_R$ is rolling resistance term coefficient, 0.012; $\rho_a$ is the air density, 1.19275 kg $m^{-3}$; $C_D$ is air resistance term coefficient, 0.00302; $m$ is the mass of the test vehicles (kg). In order to analyze the pollutant emission rate data of seven urban freight vehicles, the VSP data were divided into five different bins, namely, VSP ≤ 0, 0 < VSP ≤ 0.5, 0.5 < VSP ≤ 1, 1 < VSP ≤ 2, VSP > 2.

## RESULTS AND DISCUSSION

### *Characteristics of $CO_2$ Emission*

Fig. 2 presents the $CO_2$ emission rates of the tested vehicles in different VSP. It clearly shows that all the tested vehicles under the China IV standard emission rates increase with the elevated VSP and reach the top emission level when they are at the highest VSP situation. However, there is a valley at 0.5 < VSP ≤ 1 in terms of the test vehicles under the China IV standard and then increases again to the peak. Taking the China III-1 as an example, the $CO_2$ emission rates at different VSP bins are 3.42 g $s^{-1}$, 3.90 g $s^{-1}$, 3.12 g $s^{-1}$, 4.15 g $s^{-1}$, 5.22 g $s^{-1}$, respectively. The $CO_2$ emission rate of VSP > 2 increases 52.6% in comparison with that of VSP ≤ 0. All of the tested vehicles approach the maximum when VSP > 2, which means their fuel consumptions also increase according to the carbon balance theory, and their fuel economy get worse.

### *Characteristics of Gaseous Pollution*

Through analyzing the data obtained based on VSP bins, the gaseous pollution emission rate vs. VSP, the gaseous pollution emission rate based on $CO_2$ vs. vehicle speed and the gaseous pollution emission rate based on $CO_2$ vs. VSP are illustrated as Fig. 3, Fig. 4, Fig. 5, respectively. For both China III vehicles and China IV vehicles, it clearly shows that the CO, HC and $NO_x$ emission rates generally increase with the rising VSP. With regard to CO, HC and $NO_x$ emissions based on $CO_2$, a similar tendency is also observed for China III vehicles and China IV vehicles. Zhang *et al.* (2016b) and Huang *et al.* (2013) demonstrated that the gaseous emission rates are mainly affected by engine power rather than vehicle speed.

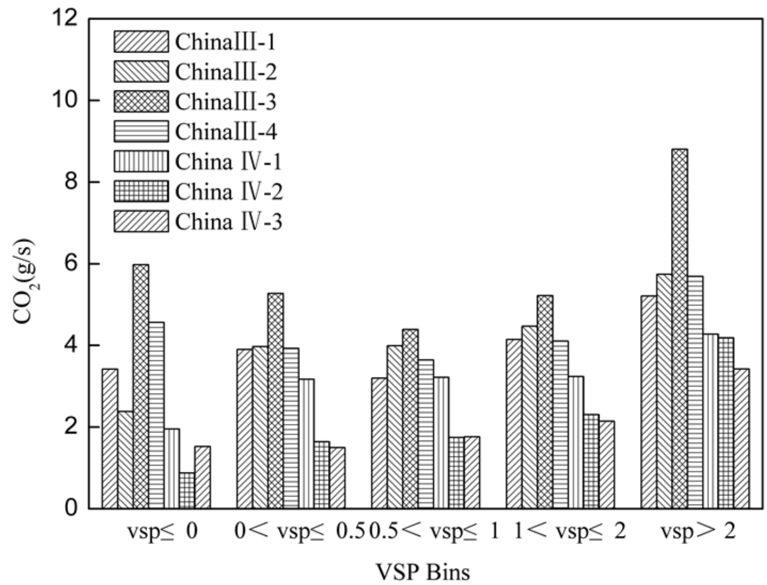


**Fig. 2.** $CO_2$ emission rates under different VSP.

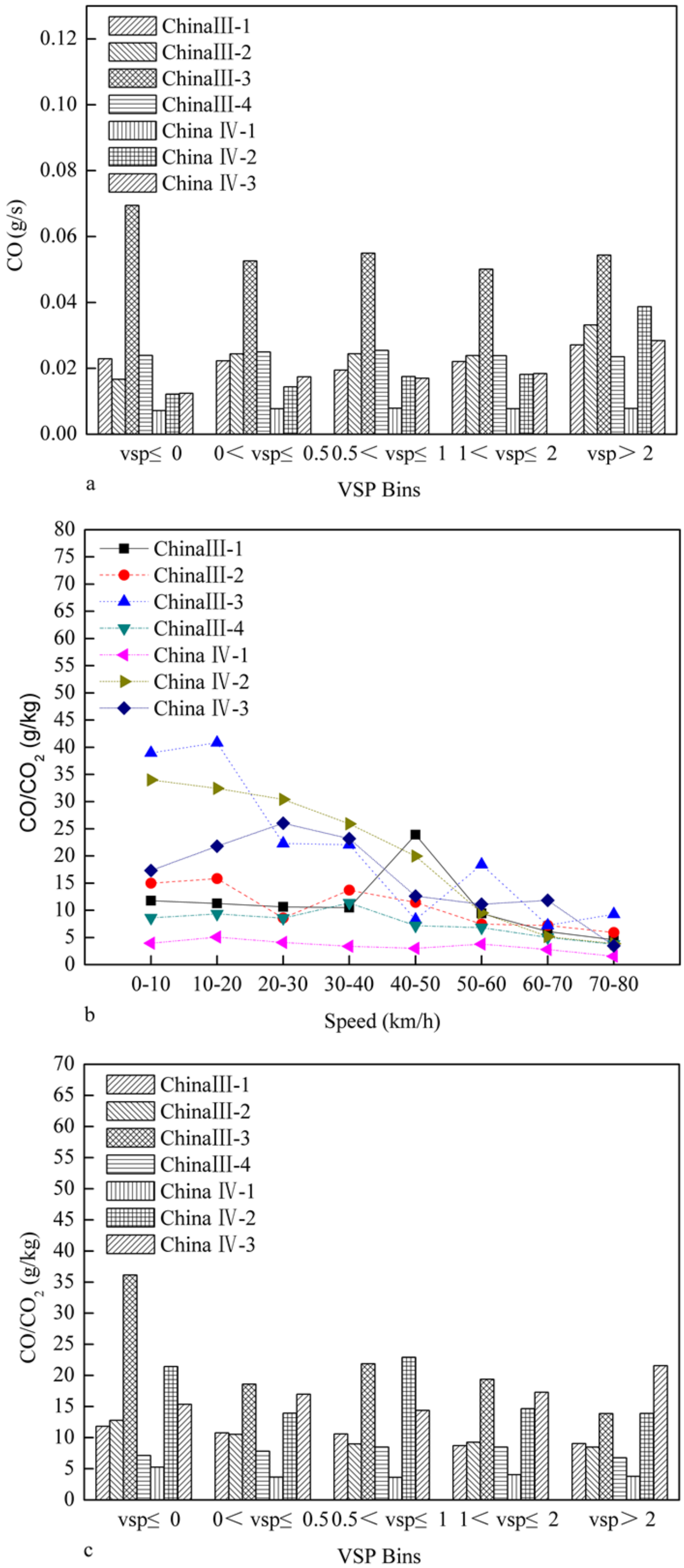


**Fig. 3.** Characteristics of CO emission rates: (a) CO emission vs. VSP; (b) CO emission based on $CO_2$ vs. Speed and (c) CO emission based on $CO_2$ vs. VSP.

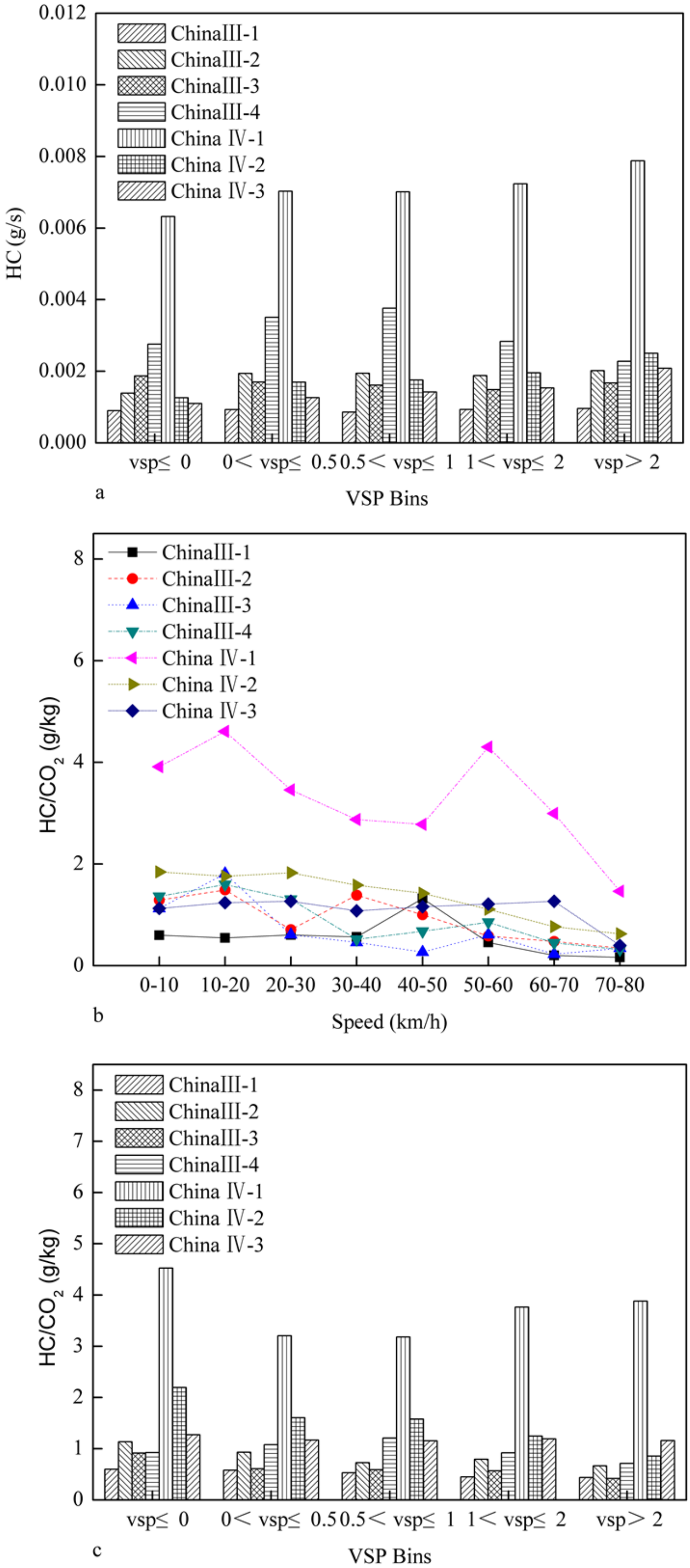


**Fig. 4.** Characteristics of HC emission rates: (a) HC emission vs. VSP; (b) HC emission based on $CO_2$ vs. Speed and (c) HC emission based on $CO_2$ vs. VSP.

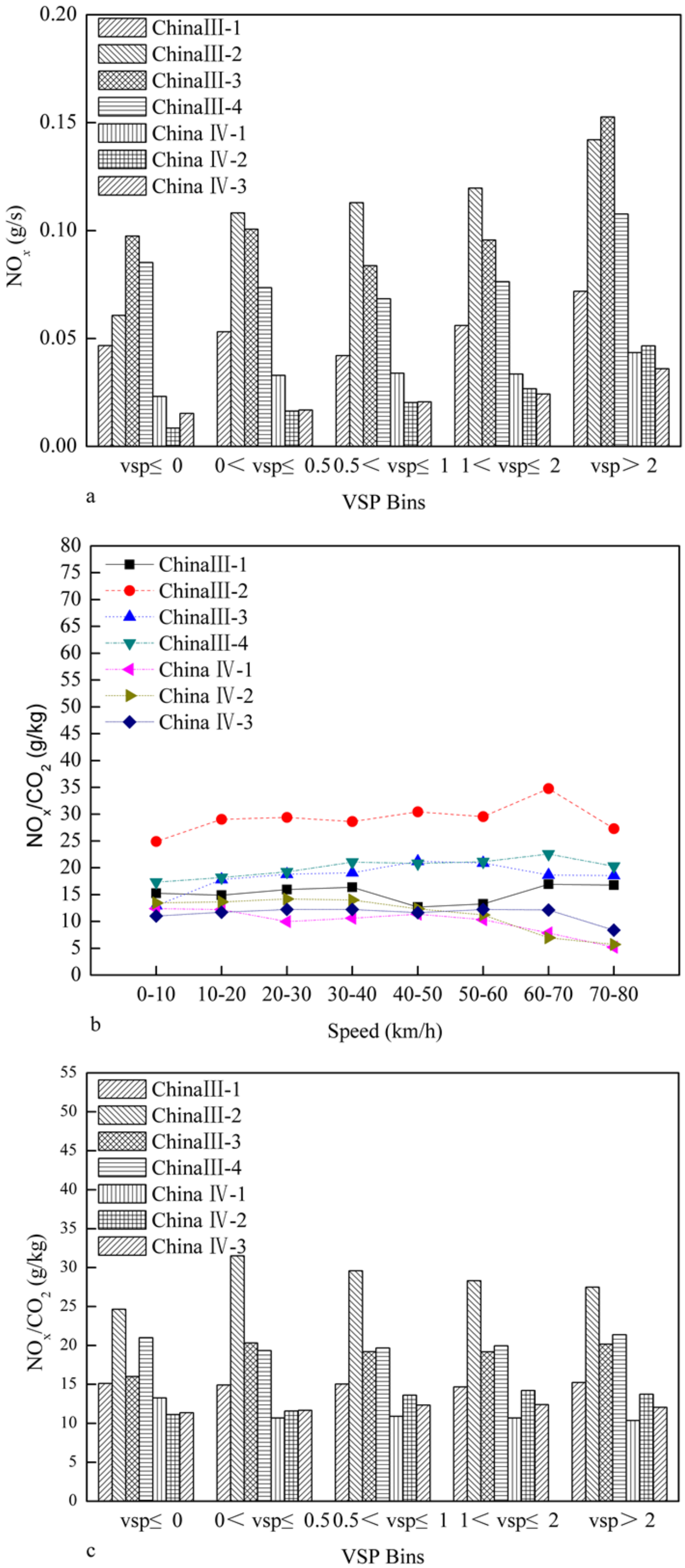


**Fig. 5.** Characteristics of $NO_x$ emission rates: (a) $NO_x$ emission vs. VSP; (b) $NO_x$ emission based on $CO_2$ vs. Speed and (c) $NO_x$ emission based on $CO_2$ vs. VSP.

For $NO_x$ emissions based on $CO_2$, as shown in Fig. 5, $NO_x$ emission in China IV vehicles are less compared with China III vehicles. This phenomenon is consistent with previous works (Huo *et al*., 2012; Wu *et al*., 2012; Yao *et al*., 2015c) and the main reason is that the installation of EGR control devices in diesel trucks (Yao *et al*., 2015c). In general, due to the presence of advanced electronic fuel injection system, the oxidation catalyst in exhaust gas after-treatment system (Yao *et al*., 2015c) in China IV vehicles, the emission rates of CO and HC should be lower compared to China III vehicles. However, there is some differences in some bins, as shown in Figs. 3 and 4 for CO and HC emissions, and additional tests should be performed in future work.

There is a decline tendency with the increasing speed and acceleration for CO emissions based on $CO_2$ in Fig. 3(b). This phenomenon occurs because vehicles need much more air and fuel to generate enough power when speed and acceleration rise. As a result, the CO emission rate becomes higher. However, the engine has become worse when speed and acceleration are low; thus, the combustion efficiency is low and the vehicle generates more CO. When the vehicles go into the condition of high speed and acceleration, mobility of air in cylinder and atomization of fuel all get better. The economy of fuel also gets better. In addition, a higher value of China III-3 vehicle can be clearly seen in the figure and the main reason is that the displacement of this truck is 4.75 L, which is far more than others.

A similar tendency to CO emission of HC emission characteristics can be found in Fig. 4(b). The causes of this phenomenon mainly comprise the following several aspects. Firstly, it is well known that the incomplete fuel combustion leads to the production of HC, and fuel is not effectively burnt, which results in higher HC emission. Secondly, the high rotation speed enhances the streaming mixture and eddy diffusion at a high speed and acceleration in the cylinder. Thirdly, part of HC would be transformed to other CO at higher temperature and the cylinder wall temperature is rising, which will shorten the quenching distance to alleviate HC production (Wu *et al*., 2012; Wang *et al*., 2016). Therefore, HC emission based on $CO_2$ decreases with the increasing speed and acceleration, while HC emission increase with the rising VSP.

As illustrated in Fig. 5(b), the value of $NO_x$ emissions based on $CO_2$ all maintain in a relatively steadfast. The changes of speed and acceleration have a very slight influence on the $NO_x$ emission based on $CO_2$. Similar results were reported by Yao *et al*. (2015c), who concluded that $NO_x$ emission level based on $CO_2$ mainly depended on the bursting state in the cylinder rather than the actual on-road driving conditions.

***Characteristics of PM Emission***

Regarded as one of the main pollutants from diesel emission, PM has attracted widespread concern (He *et al*., 2017). Characteristics of PM emission rates are shown in Fig. 6. It is known that the PM emission limit is lower with the stricter standards and the advanced after-treatment technologies are employed from China III to China IV. Thus, it is found that the PM emission rate of all China IV trucks is lower compared to all China III trucks in Fig. 6(a). In addition, as the same reasons like gaseous pollutions, it is concluded that PM emission rate and PM based on $CO_2$ increase with the growing VSP value.

## CONCLUSIONS

To better understand the emission characteristics of urban freight trucks in Beijing, the gaseous pollutants and PM were measured by using a VSP-based PEMS. The relevant conclusions drawn from this work are listed below.

(1) Both gaseous pollutants and PM emissions increase with VSP;

(2) Compared to China III vehicles, China IV vehicles emit

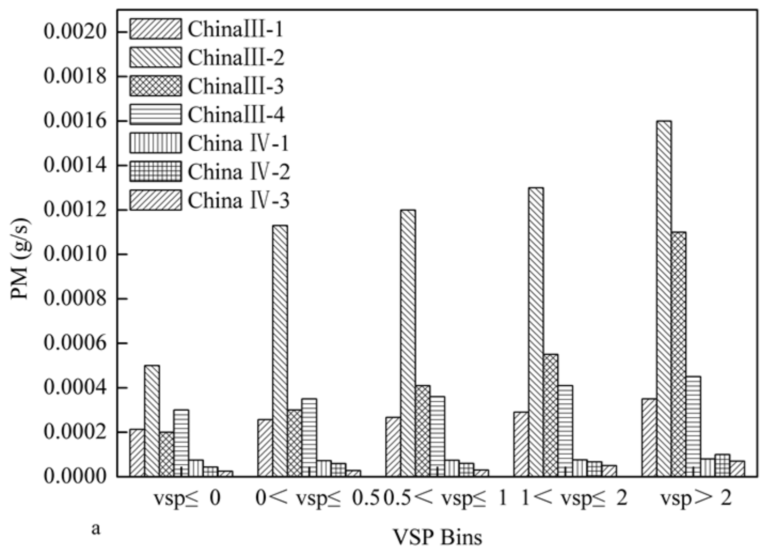


**Fig. 6.** Characteristics of PM emission rates: (a) PM emission vs. VSP; (b) PM emission based on $CO_2$ vs. Speed and (c) PM emission based on $CO_2$ vs. VSP.

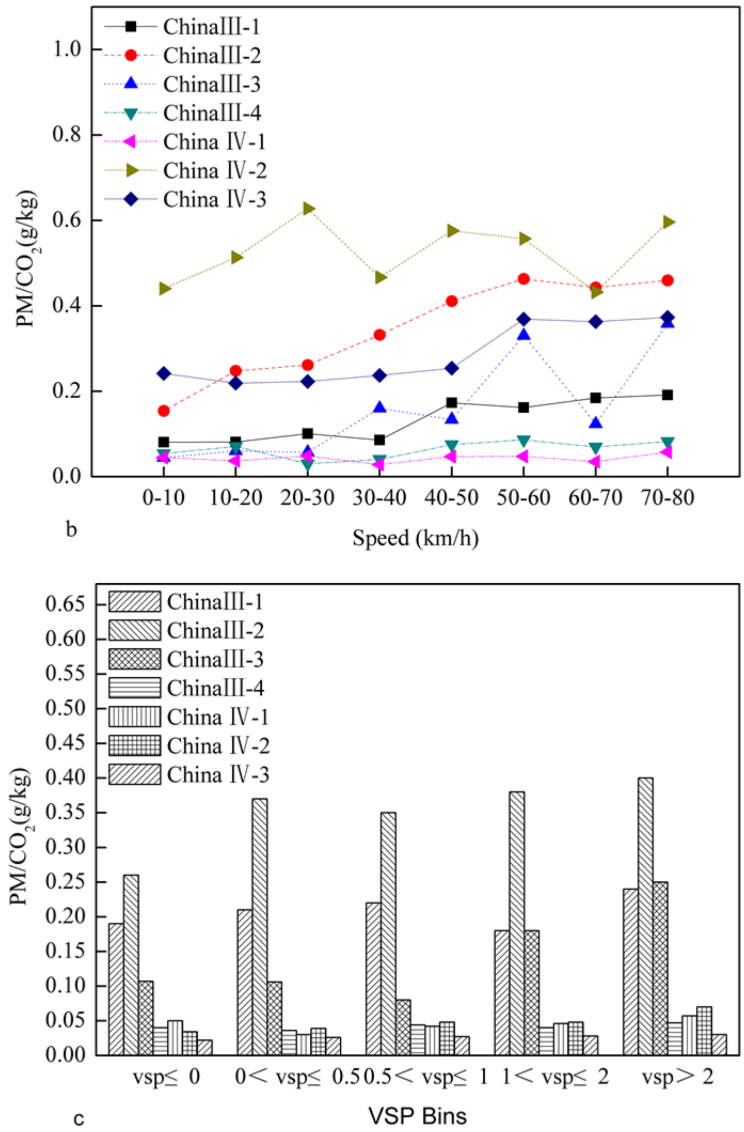


**Fig. 6.** (*continued*).

less PM and $NO_x$. Speed and acceleration have a very slight influence on the $NO_x$ emissions based on $CO_2$;

(3) Both the CO and HC emissions based on $CO_2$ tend to decline with increasing speed and acceleration;

(4) The urban freight vehicles drive under high VSP and negative VSP condition reasonably is necessary in Beijing should be avoided. Cities must not only develop more specialized roads for vehicles with special functions but also increase the penalty for illegal activity. In addition, urban freight vehicles should avoid carrying excess weight and suddenly speeding up or slowing down.

## ACKNOWLEDGMENTS

This work is conducted with funding from the project supported by the National High-tech Research and Development Program (Grant No.2016YFC0208005) and the National Natural Science Foundation of China (Grant No. 51476012).

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*Received for review, December 22, 2017*
*Revised, March 11, 2018*
*Accepted, March 19, 2018*