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Original Article

# Chinese vehicle emissions characteristic testing with small sample size: Results and comparison

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A B S T R A C T

Mobile emissions represent a main source of fine particulate matter ($PM_{2.5}$) in China, however, few studies have tested the mobile source profiles of Chinese vehicles due to the high cost. In this study, the exhaust emissions of 21 Chinese vehicles, which were divided into five groups according to weight and fuel type, were sampled using the chassis dynamometer–dilution tunnel method. $PM_{2.5}$ mass, organic carbon (OC), elemental carbon (EC) and 190 compounds of organic matter were measured to compare emission characteristics with published mobile profiles. In this study, $PM_{2.5}$ emission factors are higher for high mileage vehicles than new vehicles (255 and 115 mg/km). Among all vehicle emissions, OC averaged 55.4 ± 15.5% of $PM_{2.5}$ mass while quantified organic carbon (QOC) averaged 4.5 ± 3.0% of $PM_{2.5}$ mass. N-alkanes were the predominant species within QOC, averaging 57.0 ± 22.1% of QOCby mass. Normal-aliphatic acids, which are products of catalysis, were observed in the highest concentrations in light-duty gasoline cars. Concentrations of polycyclic aromatic hydrocarbons with more than five rings (large PAHs) differed between gasoline and diesel vehicles, suggesting that large PAHs like benzo[ghi]perylene and coronene could be used to distinguish between fuel types. Hopanes and steranes made up a relatively small fraction of QOC compared with other species (1.1%–16.7% of the total QOC mass) but the relative concentrations of hopanes were similar among different vehicle types. The observed emission characteristics in this study are comparable with a US mobile source profiles published by Lough et al. (2007).



## 1. Introduction

Vehicle exhaust is a ubiquitous pollution source in urban areas and many studies have shown its adverse health effects (Pearson et al., 2000; Vette et al., 2013). In recent years, fine particulate matter ($PM_{2.5}$) pollution has received increased attention as a global problem. Previous research has found that automotive pollutants occupy 12.6–44% of total airborne particulate matter pollution (Maykut et al., 2003; Almeida et al., 2005; Lee and Hopke, 2006; Huang et al., 2015), which showed the significance in mobile source studies. Rapid economic progress and urbanization in China in recent decades has led to a dramatic increase in the number of vehicles in China. For example, the vehicular population in Beijing almost doubled from 2007 to 2012, going from 2.73 million vehicles to more than 5 million (Wang et al., 2014). Moreover, China has relatively high single-vehicle emissions factors due to vehicle design (i.e. lack of aftertreatment) as well as urban space limitations, which concentrate serious traffic pollution in specific areas. A recent source apportionment study in Beijing showed that vehicle emissions contributed to 63.0% of the carbonaceous mass of $PM_{2.5}$ (Wang et al., 2015).

Because the measurement methods are expensive and complex, there are few mobile source profile studies that quantify mobile

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sources in China, especially for source profiles containing organic molecular markers. A chemical mass balance model (CMB), widely used in source apportionment studies, uses ambient data and source profiles to quantify each source's contribution to particulate matter (Coulter, 2004). However, without local source profiles, the CMB source apportionment model results in non-ignorable errors (Lee et al., 2008; Taiwo et al., 2014). Most source apportionment studies in China which used the CMB model, used non-local traffic profiles (Zheng et al., 2005, 2011). Although the results of these studies seem reasonable, emissions discrepancies exist between vehicles in China and developed countries, which limit the generalizability of these studies. It is necessary to understand the emissions factors of Chinese motor vehicles because of their design, which causes the average automotive emissions rate in China to be much higher than in industrialized countries. Motor vehicle emissions factors are affected by several features, such as fuel type, starting mode, ambient temperature and maintenance conditions (Rogge et al., 1993). The diversity of vehicle weights, aftertreatment and fuel injection techniques is pronounced in Chinese vehicles given the fast development of the automobile industry in recent years. Measuring source profiles of each type of vehicle rather than a unitary traffic profile is there more useful in source apportionment studies.

There are usually three ways to collect automotive emission samples: the dilution tunnel—chassis dynamometer method, field sampling and traffic tunnel sampling (Pant et al., 2014). In this paper, to achieve accurate and comparable emissions measurement results for individual vehicles, the dilution tunnel—chassis dynamometer method was selected as the preferable method. There are two goals in this study. One is to report the emissions factors of different types of vehicles as references for traffic control and environmental policy setting, Another is to compare vehicle emission characteristics between a small sample fleet (our results) and a published mobile profiles (we call them CN and US profiles in the following parts), which provides the basis for future mobile profiles measuring. We will display the vehicle emission characteristics tested in this study first then do the following comparison.

## 2. Methods

### 2.1. Sampling

Vehicles are usually classified by environmental agencies according to engine fuel types since this is usually regarded as the main factor impacting $PM_{2.5}$ emissions. Gasoline and diesel powered vehicles were tested in this study because of their prevalence in China. In addition to fuel type, vehicle design and vehicle mass also significantly influence vehicle emissions. Considering the complexity of the combustion-control technique combinations, we first classified the vehicles into two classes: heavy-duty (>3.5 ton) and light-duty (<3.5 ton). We then divided the vehicles into different groups according to their combustion-control techniques, including electronic fuel injection (EFI), carburetor (Cbrt) and catalyst (Cat). Two-wheel motorcycles were considered as an individual class given the fact that China produces and maintains the biggest motorcycle population in the world. A total of 21 vehicles were selected for testing. They were common in China with large vehicle amounts and were randomly selected to represent the real situation in China. Table S1 lists detailed information for all the vehicles tested in this study. Light vehicles and heavy vehicles produced after April, 2001 and September, 2000, respectively, follow the Chinese National Standard (GB18352.2-2001). In the test fleet, seven vehicles did not follow this standard and others did (Table S2).

### 2.2. Chassis dynamometer tests

All the chassis dynamometer tests in this study were conducted following the Chinese National Standard (GB18352.2-2001). Some cycles were modified as indicated in Table S1. To simulate the heavy traffic pressure in China, all the tests were conducted with a warm start. Briefly, there are two sections included in the procedure (Fig. S1). The first section is an ECE cycles which simulates low speed urban driving conditions; the second is an EUDC cycle which simulates high speed driving conditions in suburban areas. Before measuring, the owners of the vehicles were inquired the activity areas to determine the cycles used in the tests. Vehicle tests were started with 40 s of idle engine operation, followed by four 195 s cycles as illustrated in Fig. S1. Emissions were collected by a constant-volume sampling procedure (Fig. S2). To meet the wide range emission volume from motorcycle to heavy diesel vehicles, three venture tube (6, 9 and 12 $m^3$/min) and a secondary ten times dilution system were used in this study (Wang et al., 2005). A blank sample would be taken to correct the background influence after every five vehicle emissions samples finished.

Test cycles are usually repeated many times in most gasoline powered vehicle tests because one standard test usually does not produce enough particulate matter to exceed detection limits (Schauer et al., 2002). Therefore, strict QA/QC is important for the PM tests and the steps followed are outlined below:

1) All the sampling parts which came into contact with filters or diluted smokes were clean and wrapped with clean aluminum foil for storage.
2) Aluminum foil and quartz filters were baked at 550 °C for at least 6 h prior to use in order to remove background organics.
3) A loading blank and a system blank were inserted into the sampling sequences. Details of blank samples have been described elsewhere (Lough et al., 2007).

### 2.3. Chemical analysis

47 mm Teflon filters (GE Whatman 7592-104) were equalized in a superclean room (25 °C, 50% RH) for 48 h before and after sampling, then weighed by a microbalance (Mettler AE204). Each of them was weighed until three continuous measurements agreed within 60 μg. The average of the three masses was used. The organic carbon (OC) and elemental carbon (EC) concentrations were tested by a thermal-optical method using a Sunset Laboratory laboratory-based instrument (Sunset Laboratory Inc., NIOSH, 1996).

Particulate organic matter was collected on quartz filters and analyzed by an updated method reported by He et al. (2004). Details of the extraction and GC—MS analysis methods are described by Zhang et al. (2007). Briefly, the filters were spiked with an isotopically-labeled internal standard solution then ultra-sonicated three times with 30 ml dichloromethane/methanol (3/1 v/v) at room temperature. The extract was concentrated to ~5 ml using a rotary evaporator at 37 °C then evaporated to 1 ml under a stream of nitrogen (ultra purified, >99.9%). The concentrate was split into two fractions. Polar compounds were analyzed using an Agilent GC—MS (6890-5973N) after being derivatized with BSTFA (BSTFA/TMCS, 99:1, Supelco); non-polar and moderately polar compounds were directly measured by GC—MS.

## 3. Results and discussion

The $PM_{2.5}$ emissions factors are listed in Table S2 and the Chinese mobile source profiles are listed in Table S3. The average $PM_{2.5}$ emissions factors for gasoline-powered cars, diesel powered cars