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Influences of accumulated mileage and technological changes on emissions of regulated pollutants from gasoline passenger vehicles

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ABSTRACT

In this study, the influences of accumulated mileage (deterioration) and technological changes (emission standards) on emission factors (EFs) of regulated pollutants (CO, HC, and NOx) from gasoline passenger vehicles were investigated based on Inspection and Maintenance (I/M) data using the chassis dynamometer method. The accumulated mileage of passenger vehicles was significantly linearly correlated with vehicle age. For most cases, the average EFs of CO, HC and NOx were significantly linearly correlated with accumulated mileage, indicating that emission deterioration had a significant impact on pollutant EFs. Implemented emission standards markedly influenced the EFs of regulated pollutants, and EFs markedly decreased with progressing emission standards. The present study also compared EFs of regulated pollutants between this study and the International vehicle emission (IVE) model, and marked differences in EFs were seen with variations in emission standards, vehicle types and accumulated mileage; NOx EFs in this study were higher than in the IVE model. The results provide new insight into estimating regulated pollutant emissions using the IVE model.

Introduction

During recent decades, the rapid growth of industrialization and urbanization has led to faster increases in numbers of motor vehicles (in particular passenger vehicles) in the megacities of China; therefore, vehicle emissions constitute one of the main sources of atmospheric pollution (Guo et al., 2006; Zhou et al., 2010; Che et al., 2011; Zheng et al., 2012; Wu et al., 2017). In recent years, more frequent haze events in China have been caused by the large amount of pollutants emitted by vehicles (Huang et al., 2012; Wang et al., 2014). For example, VOC emissions in Shanghai from motor vehicles accounted for 25% of total emissions (Cai et al., 2010), and emissions of NOx in Hangzhou from motor vehicles accounted for more than 70% of total emissions (Zhang et al., 2008).

The estimation of vehicular emissions depends mainly on the values of emission factors (EFs), which are used for the development of a comprehensive emission inventory of vehicles (Mishra and Goyal, 2014). Emission factors of vehicles are dependent upon many factors such as vehicle type, fuel

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quality, vehicle age, mileage, technology level, and inspection and maintenance (I/M) (Liu et al., 2008; Liu et al., 2009, 2013; Q. Zhang et al., 2013; S. Zhang et al., 2013).

Combustion-powered vehicles tend to deteriorate with usage and accumulated mileage, and emission control equipment will be degraded or malfunction; and as a result, emission levels can elevate significantly (Lau et al., 2012; Borken-Kleefeld and Chen, 2015). The pollution degree of vehicles is mostly affected by vehicle age, and motor vehicles deteriorate with age (Zachariadis et al., 2001). Some studies reported that the deterioration of motor vehicles shows increasing trends with increases in the accumulated mileage; for example, pollutant EFs increase with accumulated mileage (Singer and Harley, 2000; Chiang et al., 2008); and 60% of the pollutants resulted from 20% of vehicles that had the highest accumulated mileages in Hangzhou city, China (Guo et al., 2006). NOx emissions from all cars and light commercial vehicles in European emission inventories were found to increase by 5%–10%, accounting for deterioration (Chen and Borken-Kleefeld, 2016).

China has adopted the European standards for new vehicles since 2001, and vehicle emission standards have played a key role in reducing vehicle emission levels in China. For example, the Beijing government has efficiently implemented emission standards and fuel quality standards, resulting in reductions in vehicle emissions (Wang et al., 2011; Zhang et al., 2014). For the Pearl River Delta region in south China, upgrading China's national IV emission standard has been the most effective individual measure to reduce average NOx and PM_{10} concentrations (Che et al., 2011). In Guangzhou during 2005–2009, vehicle emissions were estimated to have been reduced through technological improvement by 12% for CO and 21% for THC relative to levels in 2005 (Q. Zhang et al., 2013; S. Zhang et al., 2013).

The inspection and maintenance (I/M) program is one of important elements among overall measures to mitigate vehicle emissions (Wenzel, 2001; Schifter et al., 2003; Houtte and Niemeier, 2008). Many nations use vehicle I/M programs to identify high-emitting vehicles and ensure that they operate to meet emission standards (Wenzel, 2001; Schifter et al., 2003; Eisinger, 2005; Chang and Yeh, 2006; Li and Crawford-Brown, 2011). I/M programs based on periodic short tests can identify those problem cars, and require a re-test after necessary maintenance to assure their repair. Engine characteristics, vehicle age, fuel quality, mileage, and maintenance are found to be strong determinants of emissions and test failure rates (Wenzel, 2001; Eisinger, 2005). Therefore, the I/M programs contribute substantially to the reduction of pollutants caused by vehicles; Zhang et al. (2014) reported that the enhanced I/M program for light duty vehicles was estimated to reduce 11% of CO, 9% of THC and 2% of NOx relative to total vehicle emissions. Meanwhile, in-use vehicle I/M programs also generate a tremendous volume of data that provides a valuable means for evaluating the emission characteristic of vehicles (Bin, 2003; Beydoun and Guldmann, 2006; Chang and Yeh, 2006; Chiang et al., 2008). The I/M data can also be used to perform an extensive analysis of emission deterioration (Chiang et al., 2008; Chen and Borken-Kleefeld, 2016). For developing countries, it is not easy to develop EFs; furthermore, the I/M programs can be used to develop the EFs of vehicles (Schifter et al., 2003). Nowadays, China's developed cities have improved test methods and upgraded the measuring equipment for the I/M program; currently, the I/M programs have become a low-cost, highly effective, and easy test in the developed cities. The I/M stations can automatically measure vehicles on real-time basis, which gives the I/M data the accuracy necessary to evaluate the characteristics of vehicle emissions and calculate EFs for establishing an emission inventory.

China has widely used some computer models to estimate mobile source emissions for inventories, such as the international vehicle emission (IVE) model (Wang et al., 2008; Che et al., 2011; Yao et al., 2014). The IVE model is specifically designed for developing nations to address mobile source emissions, and the advantage of the IVE model is its sensitivity to existing vehicle technologies and driving behavior in developing countries (Guo et al., 2007a; Wang et al., 2008; Huo et al., 2011; Nagpure and Gurjar, 2012; Shrestha et al., 2013). The IVE model is an important tool to calculate average emission rates for different vehicle categories and facility types. However, the EFs or basic emission rates of emissions in the IVE model are U.S- and European-based, which may cause deviations in estimated emissions for developing countries (Tung et al., 2011; Kim Oanh et al., 2012). Moreover, the base EFs in the IVE model were based on data taken by a laboratory dynamometer method, with limited emission tests.

The IVE model is allowed to use local correction factors to estimate local vehicle emissions; correction EFs are important to develop improved EFs based on the IVE model (Tung et al., 2011; Kim Oanh et al., 2012; Shrestha et al., 2013). It is necessary to update the emissions in specific areas to reflect regional vehicle emissions. To our knowledge, the IVE model has not still been upgraded and is based on rather old data. In recent years, some nations have adopted modified versions of EFs based on U.S or European values.

Vehicle emissions vary with vehicle types, adopted emission standards, and emission deterioration; therefore, it is necessary to determine the factors considering parameters such as cylinder capacity, vehicle age, mileage, and emission standards.

Hangzhou, located in east China, is an important developed city with major tourist industry in China, and Hangzhou has high emission density from vehicles. The goal of Hangzhou is to become an influential international city; for example, in September 4, 2016, Hangzhou succeeded in holding the G20 summit. In coming years, Hangzhou will hold several international events, such as the 2020 Asian Games. To date, Hangzhou government has taken many measures to mitigate vehicle emissions, *i.e.*, implementing tightened emission standards, improving fuel quality, upgrading the I/M program, stringent license control, and scrappage of older vehicles.

Vehicles are mainly concentrated in cities with denser populations; urban gasoline passenger vehicles account for a high proportion of total motor vehicles in China. In 2010, the ratio of gasoline passenger vehicles to total motor vehicles in Hangzhou was 64.49% (NBSC, 2011). Therefore, it is necessary to characterize the emissions of gasoline passenger vehicles to improve the air quality of the urban environment due to low- and medium-passenger vehicles for private use and high-passenger vehicles for business use. The objectives of

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