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Heavy-duty diesel vehicles dominate vehicle emissions in a tunnel study in northern China

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HIGHLIGHTS

- Real-world emission factors for heavy-duty-diesel vehicles (HDDVs) were measured.
- Emission inventory for HDDVs and non-HDDVs were established.
- HDDVs and diesel vehicles are major sources of vehicle emissions.
- The contribution of HDDVs to fleet emissions was underestimated.

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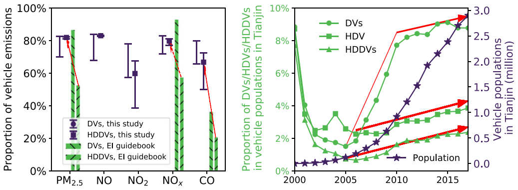
GRAPHICAL ABSTRACT



ABSTRACT

The relative importance of contributions of gasoline vehicles (GVs) and diesel vehicles (DVs), heavy-duty diesel vehicles (HDDVs) and non-HDDVs to on-road vehicle emissions remains unclear. Vehicle emission factors (EFs), including fine particulate matter ($PM_{2.5}$), NO-NO_2-NO_x, and carbon monoxide (CO), were measured (August 4-18, 2017) in an urban tunnel in Tianjin, northern China. The average EFs (mg km^{-1} veh^{-1}) of the fleet were as follows: 9.21 (95% confidence interval: 1.60, 23.07) for $PM_{2.5}$, 62.08 (21.21, 138.25) for NO, 20.42 (0.79, 45.48) for NO_2, 83.72 (26.29, 162.87) for NO_x, and 284.54 (18.22, 564.67) for CO. The fleet-average EFs exhibited diurnal variations, due to diurnal variations in the proportion of HDDVs in the fleet, though the hourly proportion of HDDVs never exceeded 10% during the study period. The reconstructed average EFs for on-road vehicle emissions of $PM_{2.5}$, NO, NO_2, and NO_x, and CO were approximately 2.2, 1.7, 1.5, 2.0, and 1.6 times as much as those in the tunnel, respectively, due to the higher HDDV fractions in the whole city than those in the tunnel. The EFs of $PM_{2.5}$, NO, NO_2, and NO_x, and CO from each HDDV were approximately 75, 81, 24, 65, and 33 times of those from each non-HDDV, respectively. HDDVs were responsible for approximately 81.92%, 83.02%, 59.79%, 79.79%, and 66.77% of the total $PM_{2.5}$, NO, NO_2, and NO_x, and CO emissions from on-road vehicles in Tianjin, respectively. DVs, especially HDDVs, are major sources of on-road $PM_{2.5}$, NO-NO_2-NO_x, and CO emissions in northern China. The contribution of HDDVs to fleet emissions calculated by the EFs from Chinese 'on-road vehicle emission inventory guidebook' were underestimated, as compared to our results. The EFs from on-road vehicles should be updated due to the rapid progression of vehicle technology combined with emission standards in China. The management and control of HDDV emissions have become urgent to reduction of on-road vehicle emissions.

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1. Introduction

Owing to rapid industrialization and urbanization, the severe and persistent air pollution in China has become an immense burden on healthcare and the economy (Song et al., 2017a,b). National air quality standards and emission control strategies are having a positive effect on air quality in China (He et al., 2017a,b). Local emission controls have great contribution to urban air quality (He et al., 2017c, 2016; Jing et al., 2016). Air pollution is becoming increasingly attributable to the growing and outdated vehicle fleet (mainly diesel vehicles) due to the refinement of industrial emission management, although total vehicle emissions have peaked and are now decreasing despite the increasing vehicle fleet size (Jiang et al., 2017; Wu et al., 2017). A growing body of evidence has emerged that specifically links exposure to traffic-related air pollution with increased health risks of the population (Sinharay et al., 2017; Cepeda et al., 2017; Chen et al., 2017; Hoek et al., 2002). On-road vehicles emit pollutants that damage health, including particulate matter (PM), specifically fine PM smaller than 2.5 microns (μm) in diameter ($PM_{2.5}$) that constitutes 90% of the PM emitted by on-road vehicles in China; and smog precursors, such as nitrogen oxides ($NO_x = NO + NO_2$), carbon monoxide (CO), and volatile organic compounds (VOCs), that contribute to the secondary formation of PM and ozone (O_3) (Jiang et al., 2017; Wu et al., 2016, 2017; Guo et al., 2014). However, it is difficult to evaluate the contribution of vehicle emissions to air pollution due to a lack of real-world vehicle emission data in China, despite vehicle emissions being important sources of health-damaging air pollutants. Accurately qualifying real-world vehicle emissions is essential to further our understanding of their impacts on urban air quality and public health (Li et al., 2017; Zhang et al., 2017b; Jing et al., 2016; He et al., 2016).

The estimation of real-world vehicle emissions requires a large amount of data, such as emission factors (EFs), traffic activity, fleet composition, and road information. Average EFs could be determined through four approaches, including emission models (such as Motor Vehicle Emission Simulator: MOVES, a European Road Transport Emission Inventory Model: COPERT, the International Vehicle Emissions model: IVE, and Mobile Source Emissions Factor: MOBILE), a chassis dynamometer, tunnel testing, and on-board testing. With the implementation of strict vehicle exhaust emission control strategies and the promotion of alternative-fuel vehicles worldwide, exhaust emission will markedly decline over the next few decades. However, emissions from non-exhaust are not well regulated. The contributions of non-exhaust emissions (including road abrasion, tire/brake wear, and road dust re-suspension) have become increasingly important in fleet emissions (Zhang et al., 2018a; Harrison et al., 2012; Thorpe and Harrison, 2008). Tunnel test might be the most idealized measure to estimate primary vehicle emissions including both exhaust and non-exhaust emissions without oxidation degradation by ultraviolet (UV) light. In addition, tunnel testing is a common method of obtaining average PM, NO_x, CO, and VOCs vehicle EFs for a typical urban fleet under actual road conditions (Zhang et al., 2018b; Lawrence et al., 2016; Cui et al., 2016; Dallmann et al., 2013; Hung-Lung et al., 2007; Jamriska et al., 2004; Hwa et al., 2002). Previous studies in China have focused on the average EFs of light-duty passenger vehicles (LDPVs, gasoline dominance) (Huang et al., 2017; Zhang et al., 2015; Shen et al., 2014) as they constitute the largest proportion of the Chinese vehicle fleet, accounting for 86.0% of the total fleet in 2016, based on 'China Vehicle Environmental Management Annual Report (2017)' (CVEMAR). However, on-road vehicles span a wide range of sizes, from light-duty vehicles (LDV), which are mostly fueled by gasoline in China, to heavy-duty vehicles (HDV), which are often diesel-powered. According to CVEMAR, diesel vehicles (DVs) constituted 10.2% of vehicle populations in China in 2016, but were responsible for over 99%, 68.7%, 12.6%, and 24.0% of all on-road PM, NO_x, CO, and hydrocarbon (HC) emissions, respectively. In Beijing, DVs contribute to over 80% to 90% and 60% of on-road PM and NO_x emissions, respectively (Shen et al., 2015; Wu et al., 2011). In addition, DVs were the key sources of organic carbon and organic aerosol based on the results of source apportionment in Beijing (Tang et al., 2018; Guo et al., 2012, 2013). Gertler (2005) reported that gasoline vehicles (GVs) are the primary sources of on-road PM emissions in the United States, based on EFs from tunnel tests. Dallmann et al. (2013) found that DVs accounted for $<$ 1% of all vehicles observed in the tunnel in the United States, but were responsible for (18 ± 3)%, (22 ± 6)%, and (45 ± 8)% of NO_x, organic aerosol, and black carbon emissions. The contribution of emissions from DVs, especially heavy-duty diesel vehicles (HDDVs), is generally underestimated as heavy-duty trucks (HDTs) are often not allowed access to the center city, where tunnel tests are often conducted.

There are discrepancies in the relative importance of contributions of GVs and DVs, HDDVs and non-HDDVs to ambient air pollutant concentrations (Dallmann et al., 2013). In 2014, the Ministry of Environmental Protection (MEP) of the People's Republic of China issued an 'on-road vehicle emission inventory guidebook' (EI guidebook), which recommended a series of vehicle EFs based on local studies. However, real-world emissions for on-road HDDVs and light-duty diesel vehicles are often underestimated and exceed certification limits (Anenberg et al., 2017; Lelieveld and Pöschl, 2017; Huang et al., 2017). The insufficient and dated data on real-world EFs from on-road vehicles lead to the uncertainty in current assessments of the relative contribution of on-road sources to the overall burden of air pollution.

China is experiencing a rapid improvement in vehicle emission control technologies, including the prioritization of public transportation policy, improvement of emission standards and fuel quality, in-use vehicle inspection and maintenance (I/M) programs, and odd-even license plate rules, all of which have improved air quality (Wu et al., 2011). However, few studies in the Beijing-Tianjin-Hebei (BTH) region have investigated real-world EFs for the on-road vehicle fleet, especially for HDDVs. The overall objective of this study was to determine local $PM_{2.5}$, NO-NO_2-NO_x, and CO EFs for the fleet, GVs and DVs, LDV and HDV, HDDVs and non-HDDVs. Moreover, we attempted to determine the relative contributions of DVs and HDDVs to overall on-road vehicle emissions under typical urban fleet structure. The results from this study enriched the database on the fleet-average emission factors of on-road vehicles for emission inventory, air quality modeling, and health effects studies, and provided new insights into the management and control of HDDV emissions in northern China.

2. Materials and methods

2.1. Tunnel description

The 2-week measurement campaign was conducted in the Wujinglu (WJL) tunnel in the central urban area of Tianjin (117°12′15″, 39°8′31″). The WJL tunnel has been in operation since 2010 and is an urban tunnel with north and south bores (three vehicle lanes and one walkway each), which are important parts of the Tianjin Railway Station Transport Hub as they effectively alleviate traffic pressure. Sampling stations were located at both the inlet and outlet of the north bore. The length of the tunnel is approximately 1.6 km, and there is a 4% downslope (upslope) approaching (exiting) the tunnel. The cross-sectional area of the tunnel is approximately 54 m^2. The vehicle speed limit in the tunnel is 40 km h^{-1}, and the average daily traffic volume is approximately 15,000 vehicles. There is no fresh air supply throughout the bores, therefore, the dilution of air pollutants was eliminated. The longitudinal jetting ventilation fans along the ceiling throughout the tunnel were inactive during the sampling periods. Ventilation was thus only induced by the flow of traffic through the tunnel and prevailing winds. As the traffic light