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Emission measurement of diesel vehicles in Hong Kong through on-road remote sensing: Performance review and identification of high-emitters☆

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ABSTRACT

A two-year remote sensing measurement program was carried out in Hong Kong to obtain a large dataset of on-road diesel vehicle emissions. Analysis was performed to evaluate the effect of vehicle manufacture year (1949–2015) and engine size (0.4–20 L) on the emission rates and high-emitters. The results showed that CO emission rates of larger engine size vehicles were higher than those of small vehicles during the study period, while HC and NO were higher before manufacture year 2006 and then became similar levels between manufacture years 2006 and 2015. CO, HC and NO of all vehicles showed an unexpectedly increasing trend during 1998–2004, in particular ≥6001 cc vehicles. However, they all decreased steadily in the last decade (2005–2015), except for NO of ≥6001 cc vehicles during 2013–2015. The distributions of CO and HC emission rates were highly skewed as the dirtiest 10% vehicles emitted much higher emissions than all the other vehicles. Moreover, this skewness became more significant for larger engine size or newer vehicles. The results indicated that remote sensing technology would be very effective to screen the CO and HC high-emitters and thus control the on-road vehicle emissions, but less effective for controlling NO emissions. No clear correlation was observed between the manufacture year and percentage of high-emitters for ≤3000 cc vehicles. However, the percentage of high-emitters decreased with newer manufacture year for larger vehicles. In addition, high-emitters of different pollutants were relatively independent, in particular NO emissions, indicating that high-emitter screening criteria should be defined on a CO-or-HC-or-NO basis, rather than a CO-and-HC-and-NO basis.

1. Introduction

Vehicle emissions are often believed to be the single largest contributor of atmospheric pollutants (Franco et al., 2013; Liu et al., 2017; Ropkins et al., 2009). To reduce vehicle emissions and improve air quality, new model vehicles are required to comply with the ever tightening emission standards through laboratory testing for type approval, such as the New European Driving Cycle (NEDC). However, the expected reduction in the NO_2 concentration at European roadside monitoring sites was not observed with the more stringent standards (Carslaw et al., 2011). In recent years, increasing evidence has been reported on the significant gap in the emissions performance between laboratory testing and real-world driving, in particular diesel vehicles.

Portable emissions measurement system (PEMS) can be used to investigate vehicle emissions performance under real-world driving conditions. Weiss et al. (2011) investigated the on-road emission rates of twelve Euro 3–5 light-duty vehicles using PEMS. The results showed that CO, HC and NO_x of gasoline vehicles and HC and CO of diesel vehicles were generally below the emission limits. However, NO_x of diesel vehicles exceeded the limits by 320 ± 90% and CO_2 surpassed the laboratory levels by 21 ± 9%. Kousoulidou et al. (2013) tested the emission rates of six Euro 3–5 vehicles under real-world driving and NEDC type-approval

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conditions using PEMS. They found that gasoline vehicle emissions were well below the emission standards. However, NO_x of diesel vehicles complied with the emission limits under NEDC conditions but constantly exceeded the limits under real-world driving conditions. Fu et al. (2013) assessed the NO_x emissions of two Euro IV buses by PEMS. Their results indicated that NO_x emission factors were 2.6–2.8, 2.3–2.7 and 2.2–2.3 times higher than the emission limits for urban, suburban and freeway driving, respectively. Degraeuwe and Weiss (2017) analysed the PEMS on-road driving emissions of seven Euro 4–6 diesel cars. It was found that the median NO_x emissions of NEDC-matched conditions exceeded the limit by 206%, while NO_x of all on-road conditions exceeded the limit by 266%. This implied that the narrow NEDC test conditions might be only responsible for part of the elevated on-road diesel NO_x emissions.

The gap between real-world driving and type-approval emissions was commonly believed to be increasing with time and the factors responsible for this gap included driving behaviours, vehicle configurations, traffic conditions, road grade and weather which were not well considered in the laboratory testing (Fontaras et al., 2017). Therefore, understanding vehicle emissions under real-world driving conditions are critical to address this gap. Although PEMS can measure a long series of emissions data under various real-world driving conditions with acceptable accuracy, the long turnover time of PEMS testing limited its application for a large number of vehicles (Lau et al., 2015) (e.g. ranged from 2 to 12 in above reviewed studies) and thus might not be able to represent a full picture of the on-road vehicles emissions. Additionally, the extra weight of PEMS may bias the measurements, especially for light vehicles (Weiss et al., 2011).

On-road remote sensing provides a non-intrusive method to measure vehicle emissions in a large scale at a relatively low cost. It has been widely used to monitor and control the on-road vehicle emissions. An early long-term remote sensing study showed that CO, HC and NO emissions decreased significantly over the period of 1997–2007 and the trend was not detailed for gasoline or diesel vehicles (Bishop and Stedman, 2008). However, recent remote sensing studies identified different emission trends of gasoline and diesel vehicles. Chen and Borken-Kleefeld (2014) measured the emissions of light duty vehicles at one site in Zurich during 2000–2012. The results showed that diesel NO_x emissions [g/kg fuel] had actually increased although emission limits had been progressively tightened. However, this discrepancy was not observed for other emissions or gasoline vehicles. Carslaw et al. (Carslaw et al., 2011; Carslaw and Rhys-Tyler, 2013) measured the NO and NO_2 emissions of on-road vehicles using remote sensing in London. They found that only gasoline vehicles showed reduction in NO_x/CO_2 over the period of 1985–2012, while diesel vehicles, including those with after-treatment systems designed to reduce NO_x, showed little evidence of NO_x/CO_2 reduction. Pujadas et al. (2017) investigated the real-world driving emissions of passenger cars in Spain. Their results showed that CO/CO_2, HC/CO_2 and NO/CO_2 of gasoline vehicles and CO/CO_2 and HC/CO_2 of diesel vehicles were decreasing from pre-Euro to Euro 6 standards, while no NO/CO_2 reduction was observed for diesel vehicles during the same period.

Research into remote sensing in Hong Kong began in 1993 and it has been used for various applications. Chan et al. used remote sensing to develop CO, HC and NO emission factors for gasoline (Chan et al., 2004), diesel (Chan and Ning, 2005) and liquefied petroleum gas (LPG) (Ning and Chan, 2007) vehicles. Lau et al. (2012) used remote sensing to monitor the vehicle emission trends in Hong Kong. It was found that CO, HC and NO emissions [g/km] of gasoline and LPG vehicles were continuously decreasing over the period of 1999–2008, while CO and NO emissions of diesel vehicles increased during 2004–2008. From 1 September 2014, the Hong Kong Environmental Protection Department (HKEPD) started using remote sensing as a legislative tool to detect high-emitting vehicles for enforcement purposes (HKEPD, accessed 17.02.2018). The high-emitters detected will be issued with an Emissions Test Notice (ETN) and are required to have the vehicles serviced/repaired and tested at an authorised emissions testing centre within 12 working days. If a vehicle failed the test, the licence would be cancelled and the vehicle would be removed from the road. However, this enforcement programme is currently only applied to gasoline and LPG vehicles, while further investigation is needed to extend this programme to diesel vehicles.

The above reviewed remote sensing studies had revealed an unexpected emission trend of diesel vehicles. However, a main limitation was that they were mostly for passenger cars and light commercial vehicles, and the number of diesel emission records in these studies were generally small. Since remote sensing only measures the snapshot emissions of a vehicle in a half second, a large sample size is needed to investigate the average emission trends accurately.

The focus of this paper is to investigate the recent emission trends of diesel vehicles and to identify the potential high-emitters based on on-road remote sensing measurement. The contribution of this study lies in the following three aspects. Firstly, we analysed a sample of 417,714 records of on-road diesel vehicle emissions from two years of continuous measurement using remote sensing technology in Hong Kong. The large sample size in this study is believed to present the diesel emission trends in a more statistically accurate manner. Secondly, this study extends the time period and vehicle class covered. The manufacture year of vehicles ranged from 1949 to 2015 and the engine size varied from 0.4 to 20 L. This large unique database allowed us to analyse the effect of manufacture year (emission standard) and vehicle category (engine size) on emissions. Finally, the emission characteristics of this study could be a good reference for setting up the high-emitting cutpoints of diesel vehicles in Hong Kong (Borken-Kleefeld, 2013) and thus help extend the enforcement programme to all the vehicles on road (HKEPD, accessed 17.02.2018).

2. Methods and data

2.1. Remote sensing setup

In this study, 14 sets of remote sensing equipment were used to collect the data. The measurements were taken at 158 sites across Hong Kong by the HKEPD from 2 January 2014 to 26 January 2016, with 40 sites in Hong Kong Island, 36 sites in Kowloon, 81 sites in New Territories and 1 site in Lantau. Fig. 1 shows the setup of one remote sensing measurement site. A measurement site should be a 5 m-width single lane with slight uphill gradient so vehicles are under constant gravity pull and away from traffic lights or intersections to avoid off cycle emissions from hard acceleration/deceleration. The site should also have sufficient traffic volume and vehicle speeds in the range of 7–90 km/h for repeatable measurements. Thousands of measurements were needed to develop and determine the site profile. This information was used to determine and validate the locations of the remote sensing units, cameras and support equipment. Two remote sensing units were placed in one measurement site with an approximately 1s separation distance. The second unit was to confirm the measurement consistency and repeatability. When the equipment was powered up and ready, a reference span gas was used to confirm that the units were operating according to the performance specifications. During the measurements, additional calibration checks were performed every 2 h with the span gas to ensure results were not