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Through-tunnel estimates of vehicle fleet emission factors

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HIGHLIGHTS

- Drive-through approach is developed to determine tunnel emission factor.
- Sen Slope method is less biased than entrance-exit approach.
- Diesel fleet emission factor is obtained with bivariate regression.

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ABSTRACT

On-road measurements of traffic-related gas and particle pollutant concentrations in three tunnels in Hong Kong and high resolution pollutant concentration profiles obtained while driving through the tunnels were used to derive the individual pollutant gradients using parametric and non-parametric (Sen–Thiel) slopes and compared with the commonly used entrance-exit two points calculation. The fuel based emission factors of measured pollutants for individual tunnels at different times of day were derived from gradients using a new method based on fuel carbon balance principle. Combined with the tunnel traffic volume and composition, the average tunnel emission factors were analyzed by linear regression to derive the diesel fleet emission factors. Average nitrogen oxides (NOx) and black carbon (BC) emission factor for diesel fleets are 29.3 ± 11.0 gNO_2 kg^{-1} and 1.28 ± 0.76 g kg^{-1} of fuel, respectively. The results from the study were compared with the emission data from vehicle chasing approaches and the literature, showing reasonable agreement. Practical limitations and future direction for improvement of our method were also discussed. The method presented in this study provides a convenient drive-through approach for fast determination of tunnel and individual vehicle fleet emission factors. It can be used as an effective and fast approach to validate the emission inventory and to evaluate the effectiveness of policy intervention on the traffic emissions.

1. Introduction

On-road vehicle emissions are an important contributor to air pollution in urban areas. In Hong Kong, vehicle emission was a major emission source of NO_x, $PM_{2.5}$ and CO accounting for 23%, 21% and 59% of total emission in 2013, respectively (HKEPD, 2015). Sound policy decision on control and management of vehicle emission depends on a reliable emission inventory and the emission characteristics of the vehicle fleets (Smit and Kingston, 2015). Vehicles emission factors (EFs) characterize the amount of pollutant emitted per mass of fuel consumed (fuel based), per distance driven (task based) or per energy used (task based). EFs change over time with for example vehicle deterioration due to accumulating mileage, implementation of more stringent emission standards, change of fuel specifications, and advance in emission control technologies (Carslaw and Rhys-Tyler, 2013; Dallmann et al., 2012). It is essential to have accurately estimated and up-to-

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date emission factors of the on-road vehicle fleets, for developing successful air quality plans to minimize impact of road transport on public health and the environment, and monitor the effectiveness of such plans.

Different methods have been developed to measure the vehicle emission factors. Chassis dynamometer methods test vehicles under controlled conditions in laboratories using standard driving cycles. Results are of high repeatability and comparability at the expense of complexity and high cost (Traver et al., 2002). This limits the number of vehicles to be tested and may not reveal a statistical characterization of the overall vehicle fleet. Moreover, the standard testing cycle may fail to reproduce real-world driving conditions (Franco et al., 2013). Portable Emissions Measurement Systems (PEMS) provide another way to measure the task-based EFs. They have the advantage of setting the equipment on-board the vehicle under investigation, which allows real-world on-road measurements (Huang et al., 2013; Weiss et al., 2011). However, measurement for light-weight vehicles may be biased by the added weight from the system (Franco et al., 2013) and the turnover time is also long, hindering broad application. Emission measurement in real-world conditions, capable of collecting large number of vehicle emissions in a short time in both task-based and fuel-based contexts, include roadside measurements (Dallmann et al., 2012; Hansen and Rosen, 1990), remote sensing (Chan et al., 2004; Chan and Ning, 2005; Ning and Chan, 2007; Singer and Harley, 2000) and tunnel studies (Cheng et al., 2006; Dallmann et al., 2012). Remote sensing systems show their effectiveness in employing the infrared and ultraviolet absorption to measure gases pollutants, but there are limitation in the measurement of particulate matter emission (Moosmuller et al., 2003). Conventional tunnel studies measure pollutant concentrations at the tunnel's entrance and exit, average emission factors of vehicles are estimated from the concentration difference of the tunnel ends (Pierson and Brachaczek, 1983; Pierson et al., 1996). Some other studies also investigated tunnel emissions at midpoint and outside as background (Kristensson et al., 2004; Nogueira et al., 2015). It is difficult to determine EFs of specific vehicle classes unless a bore is specifically dedicated to this component of the fleet (Geller et al., 2005; Jamriska et al., 2004). An advantage of tunnel studies over the remote sensing is the well-defined wind (Franco et al., 2013). On-road plume chasing approaches have been developed for the estimation of fuel-based EFs of individual vehicles (Shorter et al., 2005) and demonstrated its effectiveness in characterizing on-road emissions of various vehicle classes (Ning et al., 2012; Wang et al., 2012). On-road and roadside measurement setups have been shown to agree well (Ježek et al., 2015a).

Recently, the use of high resolution monitors in a mobile platform has allowed the characterization of tunnel concentration profiles and the estimation of the average particle number emission factors (Perkins et al., 2013). In this study, we have used a mobile platform and a drive-through approach to acquire the pollutant concentration profiles in three tunnels in Hong Kong. Different traffic characteristics in the tunnels mean different individual tunnel emission factors. Linking these with traffic volume and composition, we further calculated the diesel fleet based emission factors and compared those with results in the literature and derived using the EMission FACtors model from California Air Resources Board that modified by vehicle activity data of Hong Kong (EMFAC-HK). The study provides a method to validate the emission inventory and to evaluate the effectiveness of policy intervention on the traffic emissions.

2. Methods

2.1. Tunnels

The measurement campaign took place from spring to summer 2014 in three Hong Kong tunnels: Aberdeen, Lion Rock, and Tai Lam, as shown on the map in Fig. 1. The traffic count ratio of medium- and heavy-diesel vehicles (including double deck diesel buses and diesel goods vehicles above 5.5 tonnes) to total vehicles for Aberdeen, Lion Rock and Tai Lam Tunnels were 16%, 13% and 27%, respectively (HKTD, 2015). The tunnels selected in this study had different traffic compositions which contrasts the effect of individual vehicle classes on the tunnel emissions. The three tunnels are:

- The Aberdeen Tunnel consists of two bores each with two lanes. Both bores are 1.85-km long with slope 0.4–0.5% grade (the highest point is at the center of the tunnel). It connects Wong Chuk Hang Road and Canal Road Flyover in the Hong Kong Island. The vehicle speed limit is 70 km h^{-1} and the tunnel carries 6.5×10^4 vehicles per day (ISD, 2014);

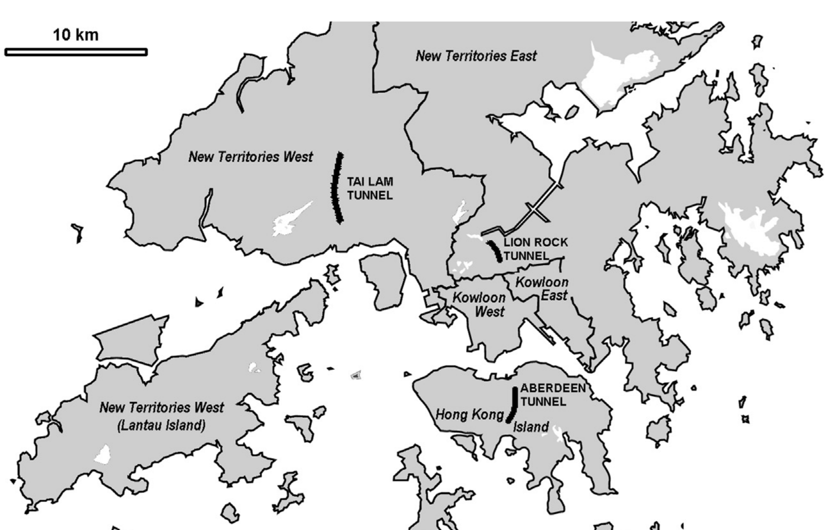

Fig. 1. Location of the three tunnels that are described in this paper. The regions marked represent the geographical constituencies of the Legislative Council of Hong Kong.