Atmospheric Environment 177 (2018) 64–74

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Decrease of VOC emissions from vehicular emissions in Hong Kong from 2003 to 2015: Results from a tunnel study

Long Cui[a], Xiao Liang Wang[b,*], Kin Fai Ho[c,d], Yuan Gao[e], Chang Liu[a,f], Steven Sai Hang Ho[b,d], Hai Wei Li[a], Shun Cheng Lee[a,**], Xin Ming Wang[g], Bo Qiong Jiang[h], Yu Huang[d], Judith C. Chow[b,d], John G. Watson[b,d], Lung-Wen Chen[i]

[a] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China
[b] Division of Atmospheric Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512, USA
[c] School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong, China
[d] Key Lab of Aerosol Chemistry and Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China
[e] Department of Civil Engineering, Chu Hai College of Higher Education, New Territories, Hong Kong, China
[f] State Key Laboratory of Severe Weather, Key Laboratory of Atmospheric Chemistry of China Meteorological Administration, Chinese Academy of Meteorological Sciences, Beijing, China
[g] State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, China
[h] School of Environmental Science and Engineering, Zhejiang Gongshang University, Hangzhou, Zhejiang, China
[i] Department of Environmental and Occupational Health, University of Nevada, Las Vegas, NV 89154, USA

ARTICLE INFO

Keywords:
Volatile organic compounds
Vehicular emissions
Tunnel
Emission factor

ABSTRACT

Vehicular emissions are one of major anthropogenic sources of ambient volatile organic compounds (VOCs) in Hong Kong. During the past twelve years, the government of the Hong Kong Special Administrative Region has undertaken a series of air pollution control measures to reduce vehicular emissions in Hong Kong. Vehicular emissions were characterized by repeated measurement in the same roadway tunnel in 2003 and 2015. The total net concentration of measured VOCs decreased by 44.7% from 2003 to 2015. The fleet-average VOC emission factor decreased from 107.1 ± 44.8 mg veh^{-1} km^{-1} in 2003 to 58.8 ± 50.7 mg veh^{-1} km^{-1} in 2015, and the total ozone (O_3) formation potential of measured VOCs decreased from 474.1 mg O_3 veh^{-1} km^{-1} to 190.8 mg O_3 veh^{-1} km^{-1}. The emission factor of ethene, which is one of the key tracers for diesel vehicular emissions, decreased by 67.3% from 2003 to 2015 as a result of the strict control measures on diesel vehicular emissions. Total road transport VOC emissions is estimated to be reduced by 40% as compared with 2010 by 2020, which will be an important contributor to achieve the goal of total VOC emission reduction in the Pearl River Delta region. The large decrease of VOC emissions from on-road vehicles demonstrates the effectiveness of past multi-vehicular emission control strategy in Hong Kong.

1. Introduction

Volatile organic compounds (VOCs), which can be primarily emitted from natural or anthropogenic sources (Atkinson and Arey, 2003; Watson et al., 2001), are important precursors of ground level ozone (O_3) formation and have adverse effects on human health (Sillman, 2002; von Schneidemesser et al., 2010). Vehicular emission is one of major anthropogenic sources of ambient VOCs in Hong Kong. In 2002–2003, vehicle- and marine vessel-related sources contributed 31–48% of ambient VOC concentrations in Hong Kong, and this contribution increased to 40–54% in 2006–2007 (Lau et al., 2010). Moreover, traffic-related sources including vehicle exhaust, gasoline evaporation and LPG usage contributed 30–60% of ambient VOCs in Hong Kong from 2005 to 2013 through a multi-year study in Hong Kong (Ou et al., 2015).

Over the past twelve years, a series of air pollution control strategies have been undertaken by the government of the Hong Kong Special Administrative Region to reduce vehicular emissions in Hong Kong. These measures mainly include: (1) tightening vehicle emission standards, (2) updating vehicle fuel standards, (3) switching diesel vehicles to liquefied petroleum gas (LPG) vehicles, and (4) retrofitting emission control devices (Lau et al., 2015). Euro 3 standard was used before

* Corresponding author.
** Corresponding author.
E-mail addresses: xiaoliang.wang@dri.edu (X.L. Wang), ceslee@polyu.edu.hk (S.C. Lee).

https://doi.org/10.1016/j.atmosenv.2018.01.020
Received 22 June 2017; Received in revised form 4 January 2018; Accepted 8 January 2018
Available online 10 January 2018
1352-2310/

2003 in Hong Kong, and it was tightened to Euro 5 standard from 2012. Vehicle fuel standard for diesel was ultra-low sulfur diesel (ULSD, 50 ppm of sulfur) before 2003 and it was updated to Euro 5 diesel standard (10 ppm of sulfur) from 2012. Gasoline fuel was also updated to Euro 5 gasoline standard from 2010. In order to control diesel vehicular emission, nearly 99% taxies were changed from diesel to LPG from August 2000 to the end of 2003. Light buses were also switched from diesel to LPG from August 2002, and about 65% light bus fleets used LPG in 2006. As a result, road transport VOC emissions in Hong Kong decreased gradually from 2003 (7600 tonnes) to 2015 (4800 tonnes) even the total vehicle kilometers traveled (VKT) in Hong Kong increased by 18.7% from 2003 to 2015.

Direct measurements in roadway tunnels is one of the methods to determine vehicular emission factors and profiles. Repeated measurements performed at the same tunnel can be used to assess the effectiveness of local vehicular emission control strategies and/or new technologies to reduce vehicular emissions (Stemmler et al., 2005). For instance, a tunnel study was conducted in Gubrist tunnel in Switzerland in 1993 and 2002, and it was found that the emission factors of particular VOCs significantly decreased after nine years, indicating the effectiveness of modern car fleets on reducing VOCs emissions (Staehelin et al., 1995; Stemmler et al., 2005). In Hong Kong, vehicular emission factors and profiles of different VOC groups (alkanes, alkenes, alkynes, and aromatic hydrocarbons) were obtained through a tunnel study in the Shing Mun Tunnel by our group in 2003 (Ho et al., 2009). In this study, experiments were repeated in the Shing Mun tunnel in 2015 to evaluate the vehicular emission reduction after 12 years in Hong Kong. Emission factors of individual VOCs are also updated in this study, which will be useful for speciated VOC inventories and related modelling studies.

2. Methodology

2.1. Sampling site

The tunnel measurements were conducted in the south bore of Shing Mun tunnel at two sampling sites: one at the inlet (Point A in Fig. 1), and the other one at the outlet (Point B in Fig. 1). The cross section area of the tunnel is 70.0 m^2, and the vehicle speed limit is 80 km h^{-1}. The tunnel has a 1% grade from the entrance to the exit. The actual vehicle speed was in the range of 60–70 km h^{-1}. The ventilation fans were not turned on during this study. Therefore, the air movement in the tunnel was mainly inducted by the piston effect of vehicle movement. More details of the sampling site was presented elsewhere (Ho et al., 2009). The inlet and outlet sampling sites were 686 m from the entrance and 350 m from the exit of the tunnel, respectively. The selection of the sampling position was based on the following three reasons, (1) inlet and outlet sampling points were set at the same position in 2015 as in 2003 to maintain the consistency, (2) the selection of sampling points should acquire the permission of related managing department, and (3) there can provide sufficient spaces for setting up other sampling instruments.

2.2. VOC collection, analysis, and gas measurement

The experiment was conducted from 19 January to 31 March 2015. From late evening to early morning (23:00–06:00 local standard time [LST]) of Monday through Thursday, one of the tunnel bores was closed for cleaning and maintenance and the traffic was routed to the other bore. On-line data collected during the maintenance period were excluded in this study.

A total of 46 pairs of VOC samples were collected in stainless steel canisters during the sampling period. One pair of samples was collected at the inlet and outlet sites simultaneously. Tunnel air was sampled from inlets located at 1.5m above the ground through Teflon tubing and collected into pre-cleaned and pre-evacuated 2 L stainless steel canisters at a flow rate of 27.3 mL min^{-1} for 2 h by a multi-port canister sampler (Model 8001, ATEC, California, USA). The sampling periods covered morning rush hour (8:00–10:00), midday (11:00–13:00 and, 14:00–16:00), and afternoon rush hour (17:00–19:00). Air samples inside canisters were firstly preconcentrated in a pre-concentrator (Model 7100, Entech Instruments Inc., California, USA) and then analyzed by a gas chromatography-mass selective detector/flame ionization detector (GC-MSD/FID) system (Model 5973N, Agilent Technologies, California, USA). Detailed analysis procedures are described elsewhere (Wang and Wu, 2008; Zhang et al., 2012). Briefly, preconcentrated air samples were firstly separated by a HP-1 column (60 m × 0.32 mm × 1.0 μm, Agilent Technologies, USA), and then separated into two streams: one went through a PLOT-Q column (30 m × 0.32 mm × 2.0 μm, Agilent Technologies, USA) which was detected by FID detector, and the other one went through a 65 cm × 0.1 mm stainless steel line followed by the MSD detector. The accuracy of the measurement was 0.5–5%, and the detection limit was 3–57 pptv for individual species.

In addition to integrated canister samples, carbon monoxide (CO), and nitrogen oxides ($NO/NO_2/NO_x$) concentrations were measured continuously (every minute) at both inlet and outlet sampling sites. CO was monitored with CO analyzers (Model 300E, Teledyne API, California, USA), and $NO/NO_2/NO_x$ was measured by $NO/NO_2/NO_x$ analyzers (Model T200, Teledyne API, California, USA). The sampling inlets of trace gas analyzers were set at 1.5m above the ground with the sampling flow rates both at 1.0 L min^{-1}.

2.3. Emission factor calculation

Emission factors (in mg veh^{-1} km^{-1}) of specific pollutants from vehicular emissions is the mass of the pollutants emitted over a certain distance normalized by the vehicle number and distance (Pierson and Brachaczek, 1982; Pierson et al., 1996).

$$EF_{veh} = \frac{(C_{outlet} - C_{inlet})\cdot A\cdot U\cdot t}{N\cdot L}, \quad (1)$$

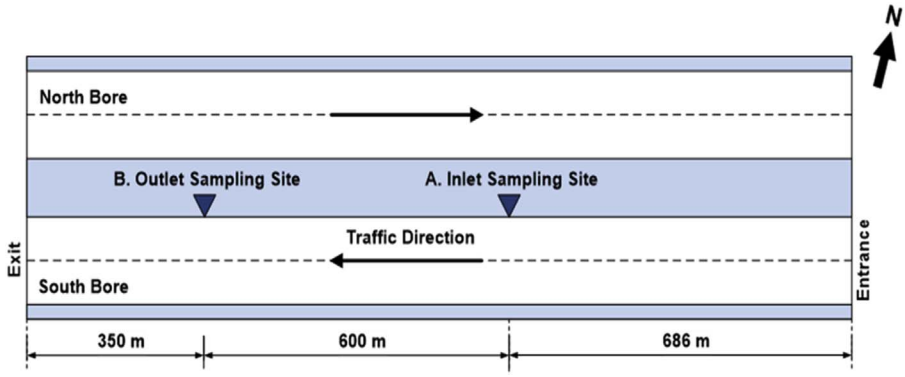

Fig. 1. Schematic diagram of Shing Mun Tunnel and sampling sites in the south bore.