Atmospheric Environment 122 (2015) 171–182

Contents lists available at ScienceDirect

Atmospheric Environment

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

Evaluation of diesel fleet emissions and control policies from plume chasing measurements of on-road vehicles

Chui Fong Lau [a,b], Agata Rakowska [a], Thomas Townsend [a], Peter Brimblecombe [a], Tat Leung Chan [c], Yat Shing Yam [d], Griša Močnik [e,f], Zhi Ning [a,*]

[a] School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong
[b] Department of Applied Science, Hong Kong Institute of Vocational Education (Chai Wan), Hong Kong
[c] Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[d] Environmental Protection Department, The Government of the Hong Kong Special Administrative Region, Hong Kong
[e] Aerosol d.o.o., Ljubljana, Slovenia
[f] Jožef Stefan Institute, Ljubljana, Slovenia

HIGHLIGHTS

- Gini coefficient was used to quantify the inequality of emission within fleets.
- Multi-pollutant control strategy needs to control vehicle emissions.
- There exist high emitters even in newer vehicle fleets.
- Identification and removal of high emitters is a cost-effective emission control.

ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form
15 September 2015
Accepted 17 September 2015
Available online 21 September 2015

Keywords:
Secondary NO_2
Particle emissions
Black carbon
High-emitters
Euro emission standards
Heavy duty diesel vehicles

ABSTRACT

Vehicle emissions are an important source of urban air pollution. Diesel fuelled vehicles, although constituting a relatively small fraction of fleet population in many cities, are significant contributors to the emission inventory due to their often long mileage for goods and public transport. Recent classification of diesel exhaust as carcinogenic by the World Health Organization also raises attention to more stringent control of diesel emissions to protect public health. Although various mandatory and voluntary based emission control measures have been implemented in Hong Kong, there have been few investigations to evaluate if the fleet emission characteristics have met desired emission reduction objectives and if adoption of an Inspection/Maintenance (I/M) programme has been effective in achieving these objectives. The limitations are partially due to the lack of cost-effective approaches for the large scale characterisation of fleet based emissions to assess the effectiveness of control measures and policy. This study has used a plume chasing method to collect a large amount of on-road vehicle emission data of Hong Kong highways and a detailed analysis was carried out to provide a quantitative evaluation of the emission characteristics in terms of the role of high and super-emitters in total emission reduction, impact of after-treatment on the multi-pollutants reduction strategy and the trend of NO_2 emissions with newer emission standards. The study revealed that not all the high-emitters are from those vehicles of older Euro emission standards. Meanwhile, there is clear evidence that high-emitters for one pollutant may not be a high-emitter for another pollutant. Multi-pollutant control strategy needs to be considered in the enactment of the emission control policy which requires more comprehensive retrofitting technological solutions and matching I/M programme to ensure the proper maintenance of fleets. The plume chasing approach used in this study also shows to be a useful approach for assessing city wide vehicle emission characteristics.

1. Introduction

On-road vehicle emission is one of the major sources of air pollution in the atmosphere, especially in urban areas. Diesel

* Corresponding author.
E-mail address: zhining@cityu.edu.hk (Z. Ning).

http://dx.doi.org/10.1016/j.atmosenv.2015.09.048
1352-2310/

fuelled vehicles of different fleets dominate in European countries (Schipper et al., 2002), while they constitute only a smaller fraction of total fleet in other areas serving mostly for goods and public transport due to their higher power rate compared with other fuelled vehicles. However, they have a disproportionally major contribution in the inventory because of their longer mileage of operation and significantly higher particulate matter (PM) emissions than vehicles using other fuels (Gertler, 2005). Furthermore, the International Agency for Research on Cancer recently classified diesel engine exhaust as a Group I carcinogen based on its association with lung cancer (Attfield et al., 2012; Silverman et al., 2012), which raises significant concerns for the public health of urban populations who tend to have frequent exposure to air pollutants from diesel exhaust. Hong Kong is a large and densely populated city, which experiences high levels of air pollution both in terms of pollutants generated on roads and that transported from the increasingly industrialised Pearl River Delta (Hagler et al., 2006; Louie et al., 2005). In 2016, tighter air quality objectives will come into force that will bring the city in line with WHO guidelines. Nevertheless the exposure patterns of Hong Kong residents, who largely live in crowded urban areas and take public transport along crowded city streets are exposed to particular combinations of pollutants that originate from traffic (Yang et al., 2015).

The government of the Hong Kong Special Administrative Region is aware of the importance of roadway vehicles as a source and has, over the years, introduced a range of regulations to reduce vehicle emissions, especially targeting diesel vehicles, as shown in Table S1. After these mandatory and voluntary based emission control measures have been successfully implemented (HKEPD, 2011, 2013), the Hong Kong Environmental Protection Department (HKEPD) has been assessing the effectiveness of the measures from the air quality data gathered by its monitoring network. However, there have been few investigations targeting their effects on on-road fleet emissions. A few studies have also pointed out the importance of proper vehicle maintenance in the effective operation of emission control devices (Edesess, 2011; Ning et al., 2012), but there has been little evidence of how Inspection/Maintenance (I/M) implementation affects aggregate fleet emissions.

The limitations are partially due to the lack of cost-effective approaches for the large scale characterisation of fleet-based emissions to assess the effectiveness of control measures and policy. For example, the chassis dynamometer method can provide comprehensive emission characteristics of individual vehicles in laboratory operation conditions (Pakbin et al., 2009), but is unable to cost-effectively test a large number of vehicles to represent the variation of emissions among the vehicle fleet (Franco et al., 2013). Portable Emissions Measurement System (PEMS) has the advantage of simulating real-world driving conditions and providing high resolution emission data (Rubino et al., 2010; Weiss et al., 2012), but the long turnover time of vehicle tests limits its application for large scale vehicle tests (Franco et al., 2013). A remote sensing system using infrared and ultraviolet absorption has proved efficient in capturing a large number of emission data in a short time (Chan et al., 2004; Ning and Chan, 2007), but there is still limitation in its application in measuring PM emission from diesel fuelled vehicles (Moosmüller et al., 2003). Recently, we have adopted a new plume chasing approach and sampled a range of vehicle fleets in Hong Kong to investigate the inter- and intra-fleet emission characteristics (Ning et al., 2012).

The current study presents a more comprehensive plume chasing campaign in Hong Kong targeting on-road diesel vehicles and also links the emissions of individual vehicles with the corresponding registration information. The principal objectives of the study are to develop a quantitative understanding of the fleet emissions issues and to elucidate the effectiveness of local emission control measures and policy. The fleet based PM and gas emission factors are presented with a quantitative measure of Gini coefficient introduced to compare the distribution of BC and NO_x emission factors and to identify the role of high-emitters in contributing to total emissions. We also investigate the degree of overlapping of high-emitters for different pollutant emissions to evaluate the effectiveness of retrofitting for emission control. Lastly, we evaluate the role of ozone in secondary NO_2 formation inside plume and present real-world ratios of primary NO_2 and NO_x from the measured heavy duty diesel.

2. Experimental methodology

2.1. Mobile platform setup

The plume chasing measurements were performed using the On-road Plume Chasing and Analysis System (OPCAS), that has been developed by our group for high time resolution on-road air quality and plume measurements. OPCAS comprises three major components: power supply module, sample analysis module, and data acquisition and processing module. Schematic diagram of OPCAS was depicted in supplementary data of the previous studies (Ning et al., 2012). It is powered by an Uninterrupted Power Supply capable for about 5-h operation. The sample analysis module was set up with separate sampling lines – one for gaseous pollutants which include CO_2, NO/NO_2 and O_3 and the other for particulate pollutants which include $PM_{2.5}$ mass, ultrafine particle (UFP) number, and black carbon (BC). Teflon tubing and fittings were used for the gas line while conductive tubing and stainless steel fittings were used for PM measurements. The details of all the measuring devices are listed in Table 1. In this study, the OPCAS was configured with an inlet installed in the front of a mobile platform towards the direction of driving to capture the plume of the target vehicle. Black carbon was measured with an Aethalometer (Model AE33, Magee Scientific) which features a parallel light absorption measurement on two sampling channels (from the same inlet stream) with different rates of aerosol accumulation to compensate filter loading effect (Drinovec et al., 2015). $PM_{2.5}$ mass concentration was measured by DustTrak II with $PM_{2.5}$ inlet connected inline and the concentrations were presented without a correction factor. The data presented in this study serves only as a reference for intercomparison among different fleets and not intended to compare with gravimetric PM emission standards. Isokinetic sampling was not considered here because particulate pollutants emitted from vehicles are of submicron size range (Morawska et al., 2007; Ning et al., 2013), with insignificant isokinetic sample error (Baron and Willeke, 2001). The ozone concentration was measured by scrubberless dual beam UV spectrometry and a Teflon filter and holder (Apex Instruments) was equipped upstream of the inlet as we found the presence of high particle concentration, especially in on-road conditions, produces biased data due to particle penetration into the gas chamber. NO and NO_2 concentrations were measured by single channel chemiluminescence method and the analyser was set with a cycle of 4s for NO and 4s for NO_x as instructed by the manufacturer for high resolution NO_x measurement.

Additionally, a high resolution Global Positioning System (GPS) was used to collect vehicle location data and speed. A camera was installed in the front window to record the on-road conditions for quality assurance while post-processing the plume chasing data, for example confirmation of on-road traffic conditions and individual emission events etc. The information on registration plate numbers of chased vehicles was recorded in the software used for chasing and voice recording was taken for quality control in case of typing error. Each day after the field operation, flow checks were performed for all the particle instruments. The gas analysers were