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SCIENCE DIRECT
Atmospheric Environment 39 (2005) 6843–6856
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

# On-road remote sensing of diesel vehicle emissions measurement and emission factors estimation in Hong Kong

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Received 22 September 2004; received in revised form 7 July 2005; accepted 26 July 2005

**Abstract**

In the present study, the real world on-road diesel vehicle emissions of carbon monoxide (CO), hydrocarbons (HC) and nitric oxide (NO) were investigated at nine sites in Hong Kong. A regression analysis approach based on the measured vehicle emission data was used to estimate the on-road diesel vehicle emission factors of CO, HC and NO with respect to the effects of instantaneous vehicle speed and acceleration/deceleration profiles for local urban driving patterns. The results show that the diesel vehicle model years, engine sizes, vehicle types and driving patterns have a strong correlation with their emission factors. A comparison was made between the average diesel and petrol vehicle emissions factors in Hong Kong. The deviation of the average emission factors of aggregate diesel vehicles reflects the variability of local road condition, vehicle traffic fleet and volume, driving pattern, fuel composition and ambient condition etc. Finally, a unique database of the correlation of diesel vehicle emission factors (i.e., $g\,km^{-1}$ and $g\,l^{-1}$) on different model years and vehicle types for urban driving patterns in Hong Kong was established.


*Keywords:* On-road vehicle emissions; Remote sensing measurement technique; Emission factors; Regression analysis

## 1. Introduction

Motor vehicle emissions are the major source of air pollution problem in most urban cities (Mayer, 1999) including Hong Kong (HKEPD, 2005). For the protection of atmospheric environment, many measurement, and control and management methods of vehicular exhaust emissions (VEEs) in urban environments have been carried out to provide criteria for determining the emission reduction and evaluating the effectiveness of vehicular emission control strategies and regulations in order to meet the clean/better air quality goals. A summary of diesel vehicle emission standard is listed in Table 1 (Tsang and Ha, 2002). On-road vehicle exhaust emissions survey using remote sensing technology offers a quick and effective method of monitoring exhaust emissions from in-use petrol vehicles under the normal driving operation. The application of remote sensing vehicle exhaust emissions testing system has been used in the polluted areas of the United States, Canada, Mexico, Australia, Taiwan, Hong Kong and many other parts of the world to achieve different tasks such as the traffic fleet and volume characterisation for the low and high emitter profiling, dirty screening programme, clean screening credit utility programme and emission inventories/factors development (Cross, 2000; Walsh, 2001; Pokharel et al., 2002; Schifter et al., 2003, 2005; Chan et al., 2004).

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1352-2310/$ - see front matter 
doi:10.1016/j.atmosenv.2005.07.048

**Nomenclature**

$a$ instantaneous acceleration/deceleration rate of diesel vehicle in $km\,h^{-1}\,s^{-1}$

$b, c, d, e, f\ldots$ constants of regression equations as defined in Eqs. (1)–(3)

$c_1, c_2, c_3, \ldots c''_4, c''_5$ constants of regression equations as defined in Eqs. (1)–(3)

$D_{fuel}$ the density of the fuel (i.e., diesel) in $kg\,l^{-1}$

$E_{i,j}$ mass emission concentration of individual emission species, $i$ (i.e., CO, HC or NO) and vehicle type, $j$ (i.e., diesel) in $g\,l^{-1}$ fuel burned as defined in Eqs. (4)–(6)

$EF_i$ emission factor of individual emission species, $i$ (i.e., CO, HC or NO) in $g\,km^{-1}$ as defined in Eq. (7)

$G_j$ fuel consumption in $l \cdot 100\,km^{-1}$ of vehicle type, $j$ (i.e., diesel) as defined in Eq. (8)

$M_{fuel}$ the molar mass of the fuel (i.e., diesel) in $kg\,mol^{-1}$

$Q$ ratio of CO to $CO_2$ in volume concentration basis as defined in Eq. (1)

$Q'$ ratio of HC to $CO_2$ in volume concentration basis as defined in Eq. (2)

$Q''$ ratio of NO to $CO_2$ in volume concentration basis as defined in Eq. (3)

$V$ instantaneous velocity of diesel vehicle in $km\,h^{-1}$

Table 1
Summary of Hong Kong diesel vehicle exhaust emission standards (Tsang and Ha, 2002)

| Implementation date/ vehicle class | 1 April 1995 | 1 April 1997 | 1 January 2001 | 1 October 2001 |
|---|---|---|---|---|
| Free acceleration smoke (light absorption coefficient $K$, $m^{-1}$) | $K$ −1.20 | $K$ −1.00 | $K$ −1.00 | $K$ −0.8[a] |
| Private car[b] | Euro I or US 88 or Japan 94 | Euro I or US 88 or Japan 94 | US California LEV | US California LEV |
| Taxi[c] | Euro I or US 88 or Japan 94 | Euro I or US 88 or Japan 94 | Banned diesel; LPG/ petrol only; EU Phase 2 or US 96 or Japan 78 | Banned diesel; LPG/ petrol only; EU Phase 2 or US 96 or Japan 78 |
| Goods vehicle and buses over 3.5 tonne | Euro I or US 91 | Euro II or US 94 | Euro II or US 98 | Euro III or US 98 |

[a]Smoke determined by ELR test for over 3.5 tonne diesels.
[b]Private Car—US California 94 as of April 1998.
[c]Taxi—Euro II as of 1 July 1999.

In order to estimate the emission contribution from on-road vehicles to urban air pollution, many vehicle emission factor models based on vehicle exhaust emission measurements have been developed and with features updated continuously such as EMFAC2002 (USCARB, 2004), MOBILE6 (USEPA, 2004), etc. Although these popular emission factor/rate models have been used widely, they could not reflect reasonably the on-road vehicle emissions of modal traffic events, real-time, site-specific emissions especially for the local vehicle exhaust emissions impact assessment due to the variations of local road condition, vehicle traffic fleet and volume, driving pattern, fuel composition and ambient condition, etc. In addition, they cannot be used effectively to evaluate the traffic control and management strategies for targeting the reduction of vehicle emissions on particular vehicle group, and neither for supporting human exposure studies in roadway environments. In recent years, many research efforts have been put in developing the new methods for the emission factor models in order to provide a better understanding of the characteristics of on-road vehicle emissions under the real-world driving patterns. The emission factors for different types of vehicles coupled with the average vehicle speed were determined under the laboratory conditions by Jost et al. (1994) and Joumard et al. (1995a, b, 2003). Sjodin et al. (1998) estimated the emission factors of many exhaust toxic gases emitted from on-road motor vehicles inside a traffic tunnel using Fourier transform infrared spectroscopy and conventional analysers. The on-board instrumentation was also used to determine the characteristics of vehicle emission