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Gaseous Pollutants Emission from Diesel Vehicles in Hong Kong

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Abstract

The current study presents the detailed investigation of diesel vehicles emissions utilizing chassis dynamometer test in Hong Kong. Gaseous pollutants from diesel vehicle exhaust, including nitrogen oxides (NO_x), total hydrocarbon (THC) and carbon monoxide (CO), are chosen to be the targets of this study. These pollutants were monitored real-time during different testing cycles and the data collected were used to calculate the fuel-based emission factor of each pollutant. Results showed that emission standard and driving conditions are the two main factors governing the trend of emission of these pollutants. Outliers observed in these trends are probably caused by the difference in level of maintenance of the vehicles, which is another important factor affecting the emission of pollutants.

Keywords: Diesel vehicle exhaust; Gaseous pollutants; Chassis dynamometers; Driving cycles

1. Background

Hong Kong is one of the most densely populated cities in the world. The vast majority of the population is exposed to traffic exhaust. In recent years, the problem of vehicle emissions has attracted increasing concern in Hong Kong since the epidemiology and toxicology studies show the evidence that vehicle emission pollutants pose serious problems for human health and the environment (Cheng et al., 2010; Dockery et al., 1993; Ou et al., 2008; Totlandsdal et al., 2012).

To tackle the air pollution problem, Hong Kong government has set up a detailed guideline on the levels of pollutants to control the air quality, known as the Air Pollution Control Ordinance. Other measures, including the introduction of European Emission Standard on vehicles, promotion of electric vehicles, tax incentives for environment-friendly private cars and commercial vehicles, and the promotion of use of biodiesel, were implemented by the government. According to the Hong Kong Environmental Protection Department (HKEPD, 2017), levels of air pollutants have greatly reduced in the last two decades. Nevertheless, it should be noted that air quality in some districts in Hong Kong still failed to meet the requirements set by the Government with all these measures implemented. Therefore, continuous monitoring of vehicle emission is needed (HKEPD, 2016).

Up till now, there have been several studies that investigate on-road or in-tunnel vehicle emissions in Hong Kong (Chan and Ning, 2005; Cheng et al., 2006, 2010; Ho et al., 2009). The current study presents the first detailed investigation of diesel vehicles emissions utilizing chassis dynamometer test in Hong Kong. Three gaseous pollutants from diesel vehicle exhaust, including nitrogen oxides (NO_x), total hydrocarbon (THC) and carbon monoxide (CO), are chosen to be the targets of this study.

2. Methods

The diesel vehicles were tested on chassis dynamometers equipped in Jockey Club Heavy Vehicle Emissions Testing and Research Centre (JCEC) in Hong Kong. Recruited vehicle fleet consist of 15 diesel vehicles that are currently running or have been run in Hong Kong, including 2 passenger cars (PCs), 5 light duty vehicles (LDVs), 6 medium duty vehicles (MDVs) and 2 heavy duty vehicles (HDVs). Tested vehicles were selected to span a wide range of emission standard, engine size, weight and model year etc. Four driving cycles including cold start transient cycle, hot start transient cycle, steady state, and idling were tested for each vehicle. Details of each vehicle can be found in Table 1. For each vehicle, 3 replicates of hot start transient cycle, steady state cycle, idling cycle and 2 replicates of cold start transient cycle were run. Transient cycles used in the current study were adapted from the type approval tests for European Emission Standard. For PCs and LDVs, NEDC (New European Driving Cycle) was used. However, for MDVs and HDVs, transient cycle used in type approval tests was ETC (European Transient Cycle), which is an engine dynamometer testing cycle. In order to fit the requirement of the current study, FIGE cycle (the chassis dynamometer version of ETC) was utilized for testing MDVs and HDVs. The speed vs time trace of NEDC and FIGE cycles were shown in Figure 1.

To simulate the real world driving conditions, loading is applied to the tested vehicles when they are running on the dynamometer. For PCs, LDVs and MDVs, 50% loading is added to simulate their normal working condition. Loading is added by means of increasing the roller resistance of the dynamometer dynamically. Due to technical hindrance, different loading factors were assigned to HDVs to ensure the feasibility of the tests. Nevertheless, these loading values can reasonably represent the real world driving condition of the vehicle.

Recruited vehicles were tested on chassis dynamometers equipped in Jockey Club Heavy Vehicle Emissions Testing and Research Centre (JCEC) in Hong Kong. Figure 2 shows a schematic diagram of the instrumental setup. All testing instruments in JCEC comply with the European standards for type approval tests. Two chassis dynamometers designed for vehicles of different weight were used in this study. For PCs and LDVs, testing was performed on a Mustang Dynamometer with 48" single roller while for MDVs and HDVs, a Mustang Dynamometer with 17.2" triple roller was used. Different analyzers (SIGNAL instruments) were used to monitor and record the instantaneous concentrations of the gaseous pollutants with frequency of 1 Hz. The detectors for THC and NOx are heat flame ionization device (Signal Model 3000HM THC Analyzer) and chemiluminescent detector (Signal Model 4000VM NOx Analyzer), respectively. For CO and CO2, non-dispersive infrared detectors (Signal Model 7100M CO IRGA Analyzer, Signal Model 7200M CO2 IRGA Analyzer) are used.

3. Results

3.1 Calculation of emission factor (*EF*)

Concentration of each gaseous pollutant was measured on-line throughout the whole test. The total amount of a certain pollutant emitted over the whole test cycle can be calculated by equation (1)

$$M_p = \sum_{i=1}^{t} C_{pi} V_i \qquad (1)$$

where,

M_p : Mass of pollutant *p* in gram [g]

C_{pi} : Background corrected concentration of pollutant *p* at i^{th} second in [g/m^3]

V_i : Volume flow of diluted exhaust through the CVS system at i^{th} second in [m^3]

t : Time duration of the test in [s]

The total amount of pollutant M_p can be used to calculate emission factors (*EFs*). One commonly employed *EF* is the amount of pollutant emitted per kilometer travelled. However, the distance specific *EFs* cannot be used to compare idling results with other tests since the tested vehicle is not running during the idling test. Therefore, a fuel-based *EF* approach is used in this study. The fuel-based *EF* is defined as the amount of pollutant emitted per kilogram fuel consumed (Miguel et al., 1998; Kirchstetter et al., 1999). The value of fuel consumption can be derived from the mass emission of CO_2. Due to the high combustion efficiency of diesel engine, it is reasonable to assume that CO_2 is the major combustion product while the contribution of other carbon containing species are negligible (Yli-Tuomi et al., 2005; Ning et al., 2008). Therefore, the fuel consumption of vehicle in a test cycle can be calculated by a simple carbon mass balance approach given by equation (2)

$$\frac{V_f \times \rho_f \times \omega_f}{MW_C} = \frac{M_{CO_2}}{MW_{CO_2}} \qquad (2)$$

where,

V_f : Volume of fuel consumed in liter [L]
ρ_f : Density of diesel fuel in [kg/L]
ω_f : Mass fraction of carbon in diesel fuel
M_{CO_2} : Background corrected mass of CO_2 produced in a test cycle in [g]
MW_C : Molecular mass of carbon in [g/mol]
MW_{CO_2} : Molecular mass of CO_2 in [g/mol]

Equation (2) is based on the fact that 1 mole of carbon atom in fuel produce 1 mole of CO_2. ρ_f is taken to be 0.832 kg/L while ω_f is taken to be 0.87 from other studies (Yli-Tuomi et al., 2005; Kirchstertter et al., 1999). The *EF* in gram per kilogram fuel consumed (g/kg) can be calculated by equation (3) after obtaining the fuel consumption V_f from equation (2)

$$EF = \frac{M_p}{V_f \times \rho_f} \qquad (3)$$

For the calculation of *EF* of NOx, the effect of ambient humidity and temperature need to be considered (Yanowitz et al., 2000; Lindhjem et al., 2004). The calculation of humidity correction factor k_h in this study is in accordance with the UNECE standard described in UNECE (2011). All NO_x data presented in this paper is humidity corrected by k_h given by equation (4)

$$k_h = \frac{1}{1 - 0.0329(H - 10.71)} \qquad (4)$$

in which:

$$H = \frac{6.211 \times R_a \times P_d}{P_B - P_d \times R_a \times 10^{-2}}$$

Where:

H : Absolute humidity expressed in grams of water per kilogram of dry air,
R_a : Relative humidity of the ambient air expressed as a percentage
P_d : Saturation vapour pressure at ambient temperature in kPa
P_B : Atmospheric pressure in the test cell in kPa

3.2 Emission standard

Figure 3 shows the *EF* results under different driving cycles for each vehicle. The effect of vehicle emission standard on gaseous pollutant emissions can be assessed by the average *EFs* over all driving conditions shown by the red dotted lines in Figure 3. It can be observed that in most of the cases, average *EFs* of CO and THC generally decrease with increasing European Emission standard. Nevertheless, some vehicles do not follow the trend (e.g. vehicle 4 and 15). This observation is probably caused by the difference in vehicle weight and maintenance status of the vehicles, which masked the effect of increasing emission standard. In the case of NO_x, since the formation mechanism of it is different from CO and THC, a different scenario was shown. For the average *EFs* of NO_x, no specific trend was observed. This observation agrees with other studies (Yanowitz et al., 2000; Huo et al., 2012; Wang et al., 2012), which arise from the different levels of maintenance of the vehicle and the strong reliance of NO_x emission with the situation of the after-treatment devices. For example, SCR of vehicle 15 was not working properly during tests and therefore its NO_x *EF* is exceptionally high, despite the fact that SCR is the leading NO_x reduction technology.

3.3 Driving Conditions

In Figure 3, it can be seen that CO, THC and NOx emissions for almost all tested vehicle show the highest fuel-based emission factors in idling condition. However, the vehicle emissions under steady state are relatively low. In transient cycles, vehicles in cold start condition generate more CO and in some cases, NOx, than hot start. Extra NOx emission in cold start cycle is found in MDVs and HDVs but not in LDVs and PCs. This observation arises from the difference in driving cycle used. FIGE cycle used for MDVs and HDVs involves more vigorous driving condition in the startup and warm-up states compared to NEDC cycle, therefore exaggerates the difference in emission between cold start and hot start condition. This effect can be illustrated by taking vehicle 1 and 13 as examples (Figure 4). For vehicle 1, real time concentrations of NO_x throughout the whole NEDC cycle do not show a significant difference between hot start and cold start conditions. The mild driving condition of NEDC cannot review the difference in NO_x concentration between hot start and cold start condition. However, for vehicle 13, which was tested by FIGE cycle, a significant increase in NO_x concentration in cold start condition is observed in the first half of the cycle, which involves vigorous accelerations and decelerations. In the second half of the FIGE cycle, the real time concentration of NO_x is more or less the same for hot start and cold start condition because in both situations, the engine has warmed up to almost the same level after the vigorous diving condition in the first half of the cycle.

4. Conclusion

Various factors have been studied for their effect of emissions on NO_x, THC and CO in diesel vehicles in this study. Emission standard of the vehicle and driving conditions are the two main factors governing the emission of these pollutants. In most of the cases, evolution of emission standard has solid effect on reducing the emission of all the gaseous pollutants. On the other hand, idling condition generates the highest fuel specific emission factor in all vehicle classes and pollutants, except NO_x emission in HDV. Transient driving cycles produce the second highest emission factor. Cold start condition in most cases produce higher emission of pollutants than hot start condition except for NO_x emission in PCs and LDVs where hot start emission has slightly higher emission factor than cold start. The above observation is attributed to the characteristic of the driving cycle used.

Last but not least, it has been observed that there are a few vehicles emitting significant amount of pollutants in spite of their high emission standard (e.g. vehicle 5 and 15). These vehicles usually have high odometer reading and inefficient after treatment device (e.g. SCR of vehicle 15 was not functioning properly), which all point to poor maintenance of the vehicle. It is expected that maintenance of engine and after treatment devices play a crucial role in controlling the emission of diesel vehicles and this should be the next topic for Government policy makers and researchers to address.

5. Acknowledgement

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6. References

Chan, T.L. and Ning, Z., 2005. On-road remote sensing of diesel vehicle emissions measurement and emission factors estimation in Hong Kong. Atmospheric Environment 39(36), 6843–6856.

Cheng, Y., Lee, S.C., Ho, K.F., Louie, P.K.K., 2006. On-road particulate matter ($PM_{2.5}$) and gaseous emissions in the Shing Mun Tunnel, Hong Kong. Atmospheric Environment 40(23), 4235–4245.

Cheng, Y., Lee, S.C., Ho, K.F., Chow, J.C., Watson, J.G., Louie, P.K.K., Cao, J.J., Hai, X., 2010. Chemically-speciated on-road $PM_{2.5}$ motor vehicle emission factors in Hong Kong. Science of the Total Environment 408, 1621–1627.

Dockey, D.W., Arden, P.C., Xu, X.P., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G., Speizer, F.E., 1993. An association between air pollution and mortality in six U.S. cities. The New England Journal of Medicine 329(24), 1753–1759.

Hong Kong Environmental Protection Department (HKEPD), 2016. Air Quality in Hong Kong 2016. Available at: http://www.aqhi.gov.hk/api_history/english/report/files/AQR2016e_final.pdf, (accessed September 2017).

Hong Kong Environmental Protection Department (HKEPD), 2017. Emission trend (1997 – 2015). Available at: http://www.epd.gov.hk/epd/english/environmentinhk/air/data/emission_inve.html, (accessed September 2017).

Ho, K.F., Ho, S.S.H., Lee, S.C., Cheng, Y., Chow, J.C., Watson, J.G., Louie, P.K.K., Tian, L.W., 2009. Emissions of gas- and particle-phase polycyclic aromatic hydrocarbons (PAHs) in the Shing Mun Tunnel, Hong Kong. Atmospheric Environment 43(40), 6343–6351.

Huo, H., Yao, Z., Zhang, Y., Shen, X., Zhang, Q., He, K., 2012. On-board measurements of emissions from diesel trucks in five cities in China. Atmospheric Environment 54, 159-167.

Kirchstetter, T., Harley, R., Kreisberg, N., Stolzenburg, M., Hering, S., 1999. On-road measurement of fine particle and nitrogen oxide emissions from light- and heavy-duty motor vehicles. Atmospheric Environment 33(18), 2955-2968.

Lindhjem, C., Chan, L.M., Pollack, A., 2004. Applying humidity and temperature corrections to on and off-road mobile emissions. 13th International Emission Inventory Conference, Clearwater, FL.

Miguel, A., Kirchstetter, T., Harley, R., Hering, S., 1998. On-road emissions of particulate polycyclic aromatic hydrocarbons and black carbon from gasoline and diesel vehicles. Environmental Science and Technology 32(4), 450-455.

Ning, Z., Polidori, A., Schauer, J., Sioutas, C., 2008. Emission factors of PM species based on freeway measurements and comparison with tunnel and dynamometer studies. Atmospheric Environment 42(13), 3099-3114.

Ou, C.Q., Hedley, A.J., Chung, R.Y., Thach, T.Q., Chau, Y.K., Chan, K.P., Yang, L., Ho, S.Y., Wong, C.M., Lam, T.H., 2008. Socioeconomic disparities in air pollution-associated mortality. Environmental Research 107(2), 237–244.

Totlandsdal, A.I., Herseth, J.I., Bølling, A.K., Kubátová, A., Braun, A., Cochran, R.E., Refsnes, M., Ovrevik, J., Låg, M., 2012. Differential effects of the particle core and organic extract of diesel exhaust particles. Toxicology Letters 208, 262–268.

UNECE, 2011. Regulation No. 83. Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements. In: Addendum 82: Regulation No. 83, Revision 4. UNECE - United Nations Economic Commission for Europe, Geneva, Switzerland.

Wang, X., Westerdahl, D., Hu, J., Wu, Y., Yin, H., Pan, X., Max Zhang, K., 2012. On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities. Atmospheric Environment 46, 45-55.

Yanowitz, J., McCormick, R., Graboski, M., 2000. In-use emissions from heavy-duty diesel vehicles. Environmental Science and Technology 34(5), 729-740.

Yli-Tuomi, T., Aarnio, P., Pirjola, L., Mäkelä, T., Hillamo, R., Jantunen, M., 2005. Emissions of fine particles, NOx, and CO from on-road vehicles in Finland. Atmospheric Environment 39(35), 6696-6706.

Table 1. *Detailed information of tested diesel vehicles.*

ID	**Class**	**Weight (kg)**	**Testing Weight (kg)**	**Manufacturer**	**Model**	**First Registration**	**Transmission type**	**Emission standard**	**After treatment devices**	**Pre-test odometer (km)**	**Engine type**	**Engine capacity**	**Engine power**
1	PC	2060	2405	Toyota	Grand Hiace	2002	4AT	EURO 3	/	337101	L4	2.982	75 kW / 3600 rpm
2	PC	2048	2485	SSANGYONG	Stavic	2016	7AT	EURO 6	EGR[1], DPF[2], DOC[3]	5883	L4	2.157	131 kW / 4000 rpm
3	LDV	1590	2195	Toyota	Hiace	2000	5MT	EURO 2	/	440048	L4	3	100 kW / 3400 rpm
4	LDV	1730	2265	Toyota	Hiace	2005	5MT	EURO 3	EGR	147635	L4	2.494	75 kW / 3600 rpm
5	LDV	2080	2650	Hyundai	H-1	2008	5MT	EURO 4	EGR	195997	L4	2.497	125 kW / 3800 rpm
6	LDV	1910	2605	Nissan	Urvan	2008	5MT	EURO 4	EGR	98999	L4	2.953	78 kW / 3800 rpm
7	LDV	1570	2150	Toyota	Hiace	2015	AT	EURO 5	EGR, DPF	15836	L4	2.982	106 kW / 3400 rpm
8	MDV	3870	4685	Isuzu	NPR	2004	5MT	EURO 3	EGR	438083	L4	4.751	110 kW / 2600 rpm
9	MDV	4850	6900	Isuzu	NPR	2005	5MT	EURO 4	EGR	318360	L4	4.751	117 kW / 2900 rpm
10	MDV	4310	4900	Isuzu	NPR	2007	MT	EURO 4	EGR, DPF	234787	L4	5.193	114 kW / 2600 rpm
11	MDV	7073	11050	Mitsubishi	Fuso	2008	6MT	EURO 4	EGR, DPF, DOC	205702	L6	7.545	140 kW / 2900 rpm
12	MDV	5670	8035	UD	MKB	2009	6MT	EURO 4	EGR	220241	L6	7.684	182 kW / 2500 rpm
13	MDV	3967	4700	Isuzu	NPR	2010	MT	EURO 5	EGR, DPF	275356	L4	5.193	116 kW / 2600 rpm
14	HGV	17680	19000	ISUZU	CYH	2008	7MT	EURO 4	EGR, DOC	390829	L6	15.681	260 kW / 2000 rpm
15	HGV	9780	23000	SINOTRUK	HOWO_A7	2012	16MT	EURO 5	SCR[4]	93232	L6	11.596	313 kW / 2200 rpm

[1] *EGR: Exhausted gas recirculation*

[2] *DPF: Diesel particulate filter*

[3] *DOC: Diesel oxidation catalysis*

[4] *SCR: Selective catalytic reduction*

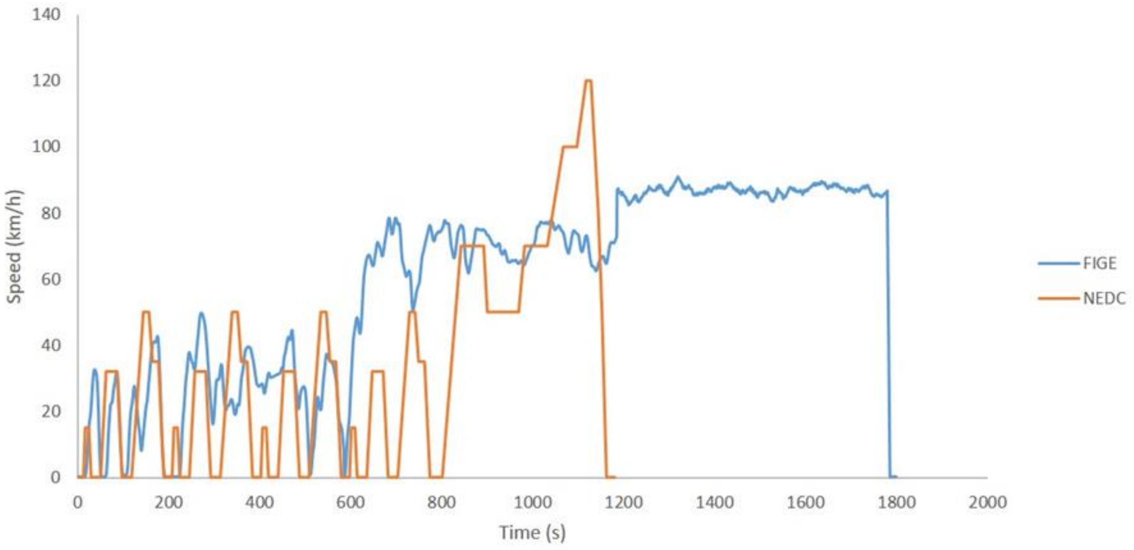

Figure 1**.** *Speed vs time trace of FIGE and NEDC cycles.*

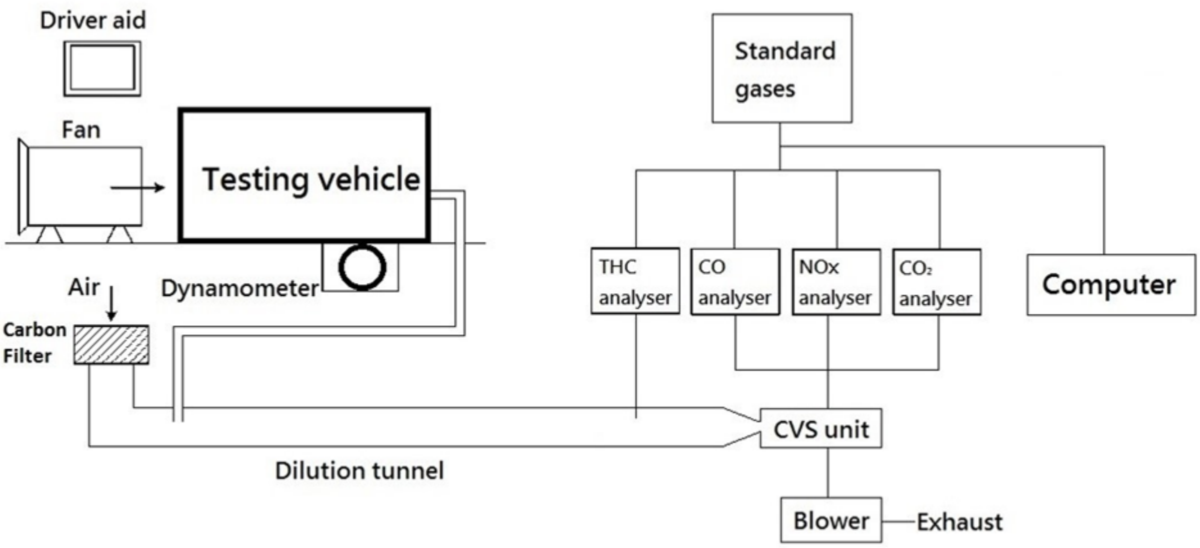

Figure 2. *Schematic diagram of the instrumental setup.*

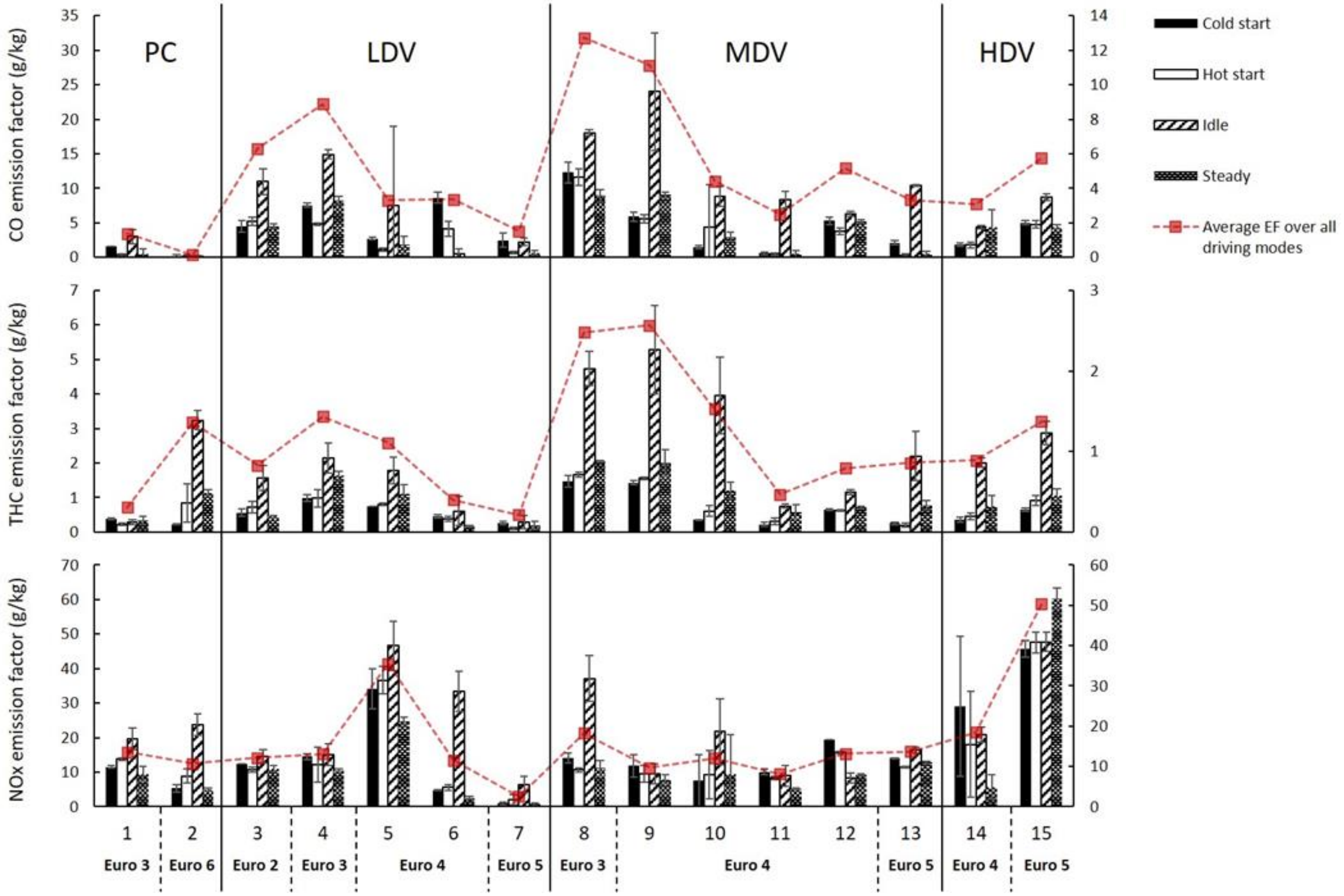

Figure 3. *EFs of three target gaseous pollutants for 15 tested diesel vehicles in different driving cycles. Red dotted line denotes the average EF over all driving cycles for each vehicle plotted on secondary axis.*

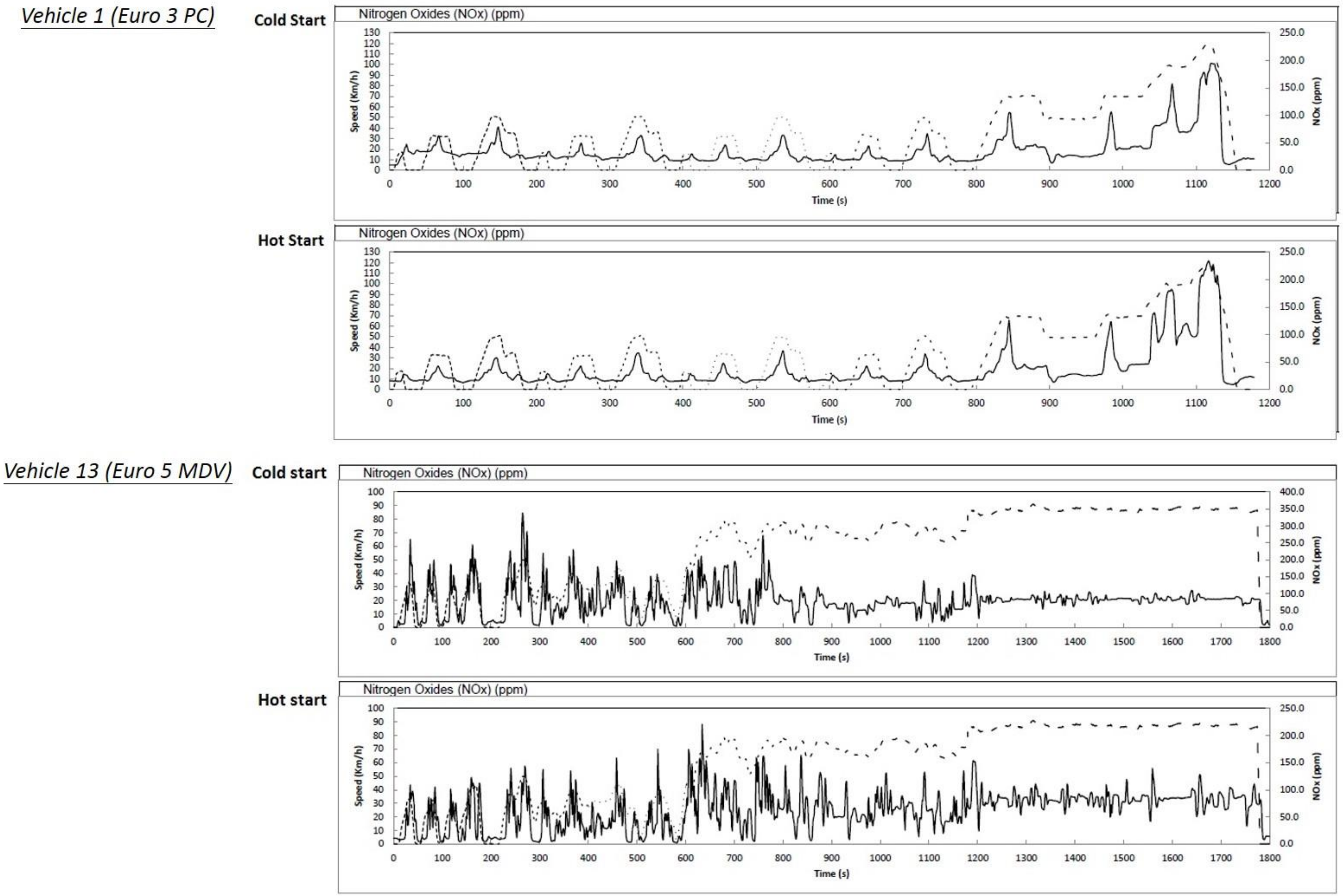

Figure 4. Real time concentration of NO_x in transient cycle tests for vehicle 1 and 13. Solid line represents the concentration of NO_x (in ppm on secondary axis) and dotted line represents the speed of the vehicle (in km/h).