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Estimation of nitrogen oxides emissions from petrol and diesel passenger cars by means of on-board monitoring: Effect of vehicle speed, vehicle technology, engine type on emission rates

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ABSTRACT

NO_X emission rates of 13 petrol and 3 diesel passenger cars as a function of average speed from 10 to 120 km/h, emission class (pre-Euro 1 – Euro 5), engine type were investigated by on-board monitoring on roads and highways of St. Petersburg using a portative Testo XXL 300 gas analyzer. The highest level of NO_X emission 0.5–2.5 g/km was inherent to old pre-Euro 1 petrol cars without a catalytic converter. NO_X emissions rates of Euro 1 and Euro 2 petrol cars changed within 0.15–0.9 g/km, Euro 3 – 0.015–0.27 g/km, Euro 4 – 0.013–0.1 g/km, Euro 5 – 0.002–0.043 g/km. Euro 3 – Euro 4 petrol cars generally satisfied corresponding NO_X Emission Standards (ES), except cold-start period, Euro 5 petrol cars did not exceed ES. Warmed, stabilized engines of Euro 3 – Euro 5 petrol cars showed 5–10 times lower NO_X emission rates than corresponding ES in the range of speed from 20 to 90 km/h. NO_X emission rates of diesel Euro 3 and Euro 4 cars varied from 0.45 to 1.1 g/km and from 0.31 to 1.1 g/km, respectively. Two examined diesel Euro 3 and one Euro 4 passenger vehicles did not satisfy NO_X ES at real use. Euro 3 diesel cars showed 28.9 times higher NO_X emissions than Euro 3 petrol cars and Euro 4 diesel car demonstrated 17.6 times higher NO_X emissions than Euro 4 petrol cars at warmed and stabilized engine at a cruise speed ranging from 30 to 60 km/h.

Introduction

Exhaust emissions from vehicles is a problem in big Russian cities (Lozhkina and Lozhkin, 2015). Nitrogen oxides (NO_X), consisting of NO and NO_2, together with particulate matter (PM), CO, SO_2, are the dominant harmful components in exhaust gases.

Nowadays, according to the national inventory data, road transport is responsible for >50% of NO_X emitted and this is due to the continuous growth of the vehicle fleet (Lozhkin and Lozhkina, 2011; Lozhkin et al., 2013).

A key gap in the understanding of these emissions is the effect of changes in vehicle speed and engine load on average emission rates for the on-road vehicle fleet (An et al., 1998; Kean et al., 2003; Lozhkina and Lozhkin, 2015).

Nitrogen oxides from vehicles are mainly formed in combustion engines at temperatures over 1700 °C (Fenimore, 1971; Miller and Bowman, 1989; Zeldovich et al., 1947). The chemical processes of their formation, transformation, and decomposition are complex and complicated (Akinyemi, 1997; Homer and Sutton, 1973; Murić, 2011):

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$$\begin{aligned} O^{\cdot} + N_2 &\rightarrow NO + N^{\cdot} \\ N^{\cdot} + O_2 &\rightarrow NO + O^{\cdot} \\ N^{\cdot} + OH^{\cdot} &\rightarrow NO + H^{\cdot} \end{aligned} \tag{1}$$

It is generally considered that most NO_X is emitted as NO (Fenimore, 1971; Lozhkin et al., 2011; Miller and Bowman, 1989; Zeldovich et al., 1947).

Most of the NO_2 in the atmosphere is formed by the reaction of NO with ozone (Bezuglaya et al., 1993; Lathan et al., 2001; Mavroidis et al., 2008; Mavroidis and Chaloulakoua, 2011; Mavroidis and Ilia, 2012):

$$NO + O_3 \leftrightarrow NO_2 + O_2^{\cdot} \tag{2}$$

At the same time NO_2 decomposes under solar radiation:

$$NO_2 + h\nu \leftrightarrow NO + O_2 \tag{3}$$

The concentration of nitrogen dioxide in the atmosphere essentially depends on the intensity of solar radiation leading to the intensification of chemical reactions.

Elevated concentrations of NO_X result in acid rains and photochemical smog. NO_2 has great adverse health effects at ambient levels in urban settings (Caballero et al., 2012; Hargreaves et al., 2000; Huang et al., 2013). Current scientific evidence links short-term NO_2 exposures, ranging from 30 min to 24 h with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma. It also contributes to cardiovascular diseases, adverse birth outcomes, premature death and cancer (Andersen et al., 2012; Beelen et al., 2008; Kan and Jia, 2003; Kan et al., 2009; Michiels et al., 2012; Qian et al., 2007; Villeneuve et al., 2012; Yorifuji et al., 2013; Yu et al., 2013).

Investigation and quantification of vehicle emissions as well as the study of their dependence on average speed is often done by laboratory chassis dynamometer tests (Alves et al., 2015; Lim et al., 2006; Mamakos et al., 2004; Ntziachristos and Samaras, 2000; Zachariadis et al., 2001; Zielinska et al., 2004). Usually, laboratory vehicle emission tests in the European Union are performed using driving cycles determined within the European ARTEMIS or NEDC projects. ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) project is based on statistical analysis of a large database of the European real-world driving patterns. The cycles include three driving schedules: (1) Urban, (2) Rural road and (3) Motorway. The NEDC (New European Driving Cycle) is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars (excluding light trucks and commercial vehicles). It is also referred to as MVEG cycle (Motor Vehicle Emissions Group). Although ARTEMIS and NEDC are widely used for the determination of pollutants emission factors, they can't fully represent real life driving conditions, such as the quality of the road, driver behavior, fuel quality, weather conditions etc. that affect pollutants emission rates, in particular, NO_X emissions rates. In this aspect, on-board monitoring is an attractive alternative tool for the determination of exhaust emissions. There have been several on-road studies, mostly performed in China (Huo et al., 2012; Ishida et al., 2003; Ropkins et al., 2007; Thang and Wang, 2006; Unal et al., 2004; X. Wang et al., 2012; Z. Wang et al., 2014; Westerdahl et al., 2009). Huo et al., 2012, measured emissions of CO, HC, and NO_X from 57 light-duty petrol vehicles (LDGVs) in three Chinese mega-cites (Beijing, Guangzhou, and Shenzhen), covering Pre-Euro 1 – Euro 4 technologies. The results show that vehicle emission technologies have played a significant role in reducing vehicle emission levels in China. The vehicle emission factors are reduced by 47–81%, 53–64%, 46–71%, and 78–82% for each phase from Euro 1 to Euro 4. Z. Wang et al. (2014) have tested 16 petrol passenger cars on roads in Macao using a portable emissions measurement system. The normalized HC, CO and NO_X emission levels of the seven passenger cars older than 2000 were 3.19 ± 5.04, 14.59 ± 22.88 and 2.57 ± 2.12 g/km, respectively. The HC, CO and NO_X emission levels of other newer vehicles were 0.02 ± 0.02, 0.23 ± 0.29 and 0.10 ± 0.13 g/km, respectively. All cars were tested at a speed less than 80 km/h.

In order to estimate traffic NO_X concentrations in a realistic context, it is necessary to establish generalized functions to represent the emissions from the whole mixed traffic flow. Emission functions are often expressed in terms of two main variables: the type of vehicles and the average speed at which it is driven. Vehicle type takes into account features of the vehicle that influence its emissions such as engine type, weight, emission technology, fuel used etc. The average speed is well correlated with the operational aspects that have a more direct effect on emissions such as gear selection, engine speed, rate and frequency of acceleration and deceleration. Average-speed functions are widely used to estimate NO_X exhaust emissions from road vehicles in regional and national inventories and are also incorporated into many air pollution prediction models on local or street scale (Gkatzoflias et al., 2012; Methodology, 2010; Settlement instruction, 2008). The problem of specification of nitrogen oxide emission rates from passenger cars depending on speed in real driving conditions is still relevant.

Thus, the aim of the present study was to estimate "real life" NO_X emission rates for passenger cars as a function of average speed (from 10 to 120 km/h), vehicle technology (pre-Euro 1 – Euro 5), engine type (petrol, diesel) in real traffic. That is very important for the correction of NO_X emission factors, for the assessment of air pollution by exhaust NO_X, for the further development of vehicle and fuel technologies.

Material and methods

Vehicles

The analysis of statistics on the vehicle fleet structure in St. Petersburg (Lozhkin et al., 2013) showed that: