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On-road measurement of NH_3 and N_2O emissions from a Euro V heavy-duty vehicle

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HIGHLIGHTS

- NH_3 and N_2O on-road emissions can be measured using a QCL-IR.
- Substantial NH_3 and N_2O emissions were observed.
- Current regulatory emissions evaluation for HD could be applied for NH_3 and N_2O.

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ABSTRACT

The use of selective catalytic reduction systems (SCR) to abate NOx vehicular emissions brings new concerns on the emissions of the byproducts NH_3 and N_2O. Therefore, NH_3 and N_2O on-road emissions from a Euro V truck equipped with a SCR were measured in real time using a QCL-IR. Results bring to light possibility to perform this kind of real time measurements for other pollutants besides, hydrocarbons, NOx, CO and CO_2. The capability to measure NH_3 and N_2O in a second-by-second basis will allow applying the currently agreed regulatory emissions evaluation for gaseous compounds. Average N_2O emission factors calculated applying the current PEMS-based data analysis to all available windows from the tests ranged from 0.063 g/kWh to 0.139 g/kWh. Average NH_3 concentrations ranged from 0.9 ppm to 5.7 ppm. Although calculated average N_2O and NH_3 emissions were within current limits, NOx emissions were substantially higher than Euro V limits under the studied conditions.

1. Introduction

According to the latest edition of the European Environment Agency's (EEA) annual report, European policies have led to an overall improvement on air quality. However, the transport sector still generates harmful levels of air pollutants. Air pollution is an important environmental health hazard, resulting in health problems for the population and high costs for health care systems (European Environmental Agency, 2014). The population living in most of the European cities is exposed to pollution levels deemed unsafe by the World Health Organization (WHO). In fact, the recent Global Burden of Disease study indicates that in western, central and eastern Europe (the WHO European Region), half million premature deaths could be attributed to exposure to ambient air pollution in 2012 (World Health Organization, 2013). More than 95% of the urban population is exposed to unsafe levels of pollutants such as: particle matter (PM), NOx and ground-level (tropospheric) ozone (O_3). In addition to causing premature death, air pollution has both long- and short-term health effects, increasing the incidence of a wide range of respiratory and cardiovascular diseases. Alongside health, these pollutants also have a significant impact on plant life and ecosystems. The European Environment Agency has stated that, at present, PM and ground-level O_3 are Europe's most problematic pollutants in terms of harm to human health, followed by nitrogen dioxide (NO_2). In terms of damage to

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ecosystems, the most harmful air pollutants are ground-level O_3, ammonia (NH_3) and NOx.

The transport sector is the largest contributor to NOx emissions and an important source of volatile organic compounds VOCs. PM is either directly emitted to the atmosphere (primary PM), or formed in the atmosphere (secondary PM). The main precursor gases for secondary PM are SO_2, NOx, NH_3 and VOCs. These compounds react in the atmosphere to form ammonium, sulphate compounds, and nitrate compounds. They account for up to 40% of the $PM_{2.5}$ in some European cities (Sillanpää et al., 2006). $PM_{2.5}$ emissions accounted for up to 78% of the reported PM_{10} emissions from transport in 2012 (European Environmental Agency, 2014). Numerical simulations performed by the Institut National de l'Environnement Industriel et des Risques (INERIS) and measurements of the chemical composition of PM showed that ammonium nitrate was a main contributor to an air pollution episode that affected France, southern United Kingdom, Belgium, the Netherlands and Germany in 2014 (European Environmental Agency, 2014). Ammonium nitrate resulted from the chemical reaction between NH_3, whose emissions were due to agricultural fertilizer spreading during this period, and NOx emissions coming from road traffic. Besides being one of the major precursors of $PM_{2.5}$, NH_3 emissions are also related with the hypertrophication of water and acidification of soils (Bouwman et al., 2002; Erisman et al., 2003; Sutton et al., 2000). Hence, an increase of NH_3 emissions due to introduction and use of some emission abatement technologies (e.g., selective catalytic reduction) may lead to a harsh detriment of urban air quality.

N_2O is a well-known powerful greenhouse gas. It has 298 times the global warming potential of CO_2 over 100 years. Furthermore, N_2O is nowadays the single most important ozone-depleting substance (ODS) (Ravishankara et al., 2009).

PM, NO_2 and O_3 are considered to be the Europe's most problematic pollutants in terms of harm to human health, and the road transport sector is considered to a major contributor to PM and NOx pollution in the European cities, where the density of population is higher (80% of the European population are city dwellers) (Eurostat. Statistics, 2015). For that reason, the European legislation has mainly aimed at reducing PM and NOx emissions from vehicles, with the introduction of Euro V/5 and Euro VI/6 emissions standards. In order to comply with the new standards, new after-treatment systems have been developed and are now used among the cars and trucks fleets. While diesel particle filters (DPF) are commonly used to reduce direct PM emissions, selective catalytic reduction systems (SCR) are one of the preferred technologies to abate NOx. The use of SCR brings new concerns on the emissions of pollutants, and air pollution because diesel vehicles, which are equipped with this system, will emit unknown amounts of NH_3 and N_2O, besides NO, NO_2, CO_2, CO, hydrocarbons and PM.

As the development of new technologies shape the new reality for the efficiency of internal combustion engines, clean diesel engines and vehicles remain a key to achieve the ambitious objectives set by the EU for the reduction of greenhouse gas and pollutant emissions at the horizon 2020.

Changes in the perspective of the European citizen towards the pollution produced by their means of transportation, combined with the lack of significant changes on the measured concentrations of pollutants in the cities, have succeeded in the legislator imposing more restrictive emissions limits. It also has encouraged the introduction of Portable Emissions Measurement System (PEMS) and their use in the measurement of second-by-second emissions during on-road operation for heavy-duty vehicles as a means to ensure compliance with the legislation over the useful life of the engines (European Commission, 2011).

The heavy-duty Euro VI Regulation (EC) No 595/2009 (European Commission, 2011) and its implementing Regulation (EC) 582/2011 introduced a procedure for testing using PEMS as a mandatory part of the type approval legislation in order to check the conformity of heavy-duty engines with the applicable emissions certification standards during the normal life of those vehicles: this is the so-called "In-Service Conformity" (ISC) requirement. In addition, Euro VI vehicles also have to comply with "off-cycle" in-use emissions (i.e., emissions measured during tests different to the type-approval cycles, such as the World Harmonized Transient Cycle, WHTC, used for the Euro VI) requirements already at type approval through the PEMS demonstration test. Regulation (EC) 582/2011 also describes the provisions for vehicles type approved under directive 2005/55/EC (Euro V) to be able to be tested using PEMS.

NH_3 and N_2O emissions are not regulated for Euro V vehicles in Europe. Nonetheless, NH_3 has a regulatory limit of 10 ppm weighted average over the type approval cycle applicable for Euro VI (European Commission, 2011). Furthermore, U.S. Environmental Protection Agency (EPA) has recently developed a GHG emissions program, under the Clean Air Act, that includes N_2O emission standards of 0.10 g/bhp-h (0.133 g/kWh) measured over the Heavy-Duty Engine FTP cycle (U.S. Environmental Protection Agency, 2015). This limit is applicable in the US since 2014 for compression ignition heavy-duty engines and from 2016 for spark ignition engines.

The purpose of the present study was to demonstrate the capability to measure NH_3, N_2O emissions second-by-second and during on-road operation from HDVs, as currently done for the other gaseous pollutants using PEMS. The second-by-second measurement during on-road operation allows analyzing emissions on different driving conditions with real on-road variables (e.g. traffic, different altitudes, weather, etc.). The possibility to do so opens the door to a more detailed observation of the different factors that affect the emissions while vehicles are being used in different urban, rural or motorway locations and conditions, which is of major importance. Furthermore, being able to measure these pollutants in a second-by-second basis will also allow applying to NH_3 and N_2O the currently agreed regulatory emissions evaluation methods described in Reg (EC) 582/2011. Hence, we present a comprehensive analysis of the on-road obtained data, NOx, NH_3 and N_2O, in different ways reflecting the effect of the boundaries with which current legislation is limiting the PEMS based test. This seemed important as current boundaries have been proven to leave non-negligible emissions out of the analysis (Perujo Mateos Del Parque and Mendoza Villafuerte, 2015).

2. Experimental

2.1. Analytical instrumentation

In the present work, real time on-road exhaust emissions from a Euro V heavy-duty diesel vehicle equipped with a SCR, urea-based DeNOx system, has been comprehensibly studied by combining measurements performed using PEMS instrumentation, GPS system, ECU data acquisition tool and a quantum cascade laser infra-

Table 1
Vehicle features.

N3 vehicle	
Emissions category	Euro V
Engine type	11 lt
Max. power	343 kW
Payload	50%
Fuel	Diesel
ETC ref work	55 kWh
After treatment	DPF + SCR