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Gaseous emissions from a heavy-duty engine equipped with SCR aftertreatment system and fuelled with diesel and biodiesel: Assessment of pollutant dispersion and health risk

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HIGHLIGHTS

- Emission, dispersion and risk assessment from Euro 5 engine by diesel and biodiesel.
- All fuels increased NH_3 and N_2O emission due to SCR use, a precursor secondary inorganic aerosol and a major greenhouse gas, respectively.
- Dispersion results showed that the SCR system double the NH_3 urban background.
- Chronic hazards due to NH_3 higher emissions were identified.

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ABSTRACT

The changes in the composition of fuels in combination with selective catalytic reduction (SCR) emission control systems bring new insights into the emission of gaseous and particulate pollutants. The major goal of our study was to quantify NO_x, NO, NO_2, NH_3 and N_2O emissions from a four-cylinder diesel engine operated with diesel and a blend of 20% soybean biodiesel. Exhaust fume samples were collected from bench dynamometer tests using a heavy-duty diesel engine equipped with SCR. The target gases were quantified by means of Fourier transform infrared spectrometry (FTIR). The use of biodiesel blend presented lower concentrations in the exhaust fumes than using ultra-low sulfur diesel. NO_x and NO concentrations were 68% to 93% lower in all experiments using SCR, when compared to no exhaust aftertreatment. All fuels increased NH_3 and N_2O emission due to SCR, a precursor secondary aerosol, and major greenhouse gas, respectively. An AERMOD dispersion model analysis was performed on each compound results for the City of Curitiba, assumed to have a bus fleet equipped with diesel engines and SCR system, in winter and summer seasons. The health risks of the target gases were assessed using the Risk Assessment Information System For 1-h exposure of NH_3, considering the use of low sulfur diesel in buses equipped with SCR, the results indicated low risk to develop a chronic non-cancer disease. The NO_x and NO emissions were the lowest when SCR was used; however, it yielded the highest NH_3 concentration. The current results have paramount importance, mainly for countries that have not yet adopted the Euro V emission standards like China, India, Australia, or Russia, as well as those already adopting it. These findings are equally important for government agencies to alert the need of improvements in aftertreatment technologies to reduce pollutants emissions.

1. Introduction

Recent changes in Brazil regarding fuel composition such as lower sulfur content of diesel and use of biodiesel blends and, more importantly, the use of engine and emission control technologies bring new insights concerning the emission of gaseous and particulate pollutants to the atmosphere.

Forthcoming European legislation and current U.S. legislation pertaining to heavy-duty diesel engines aims at the simultaneous reduction of particles and NO_x following recent air quality guidelines. To this end, new aftertreatment systems have been used and, as a result,

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the sulfur content of the fuels had to be decreased. According to the European Commission (European Commission, 2011), all petrol and diesel sales in the European Union are currently of low-sulfur (sulfur content of less than 50 ppm) or ultra-low sulfur (sulfur content of less than 10 ppm) diesel, namely, LSD and ULSD, respectively. In the United States, EPA's Clean Air Highway Diesel final rule requires a 97% reduction in diesel fuel sulfur content, from 500 ppm to 15 ppm (U.S. Environmental Protection Agency, 2013a).

Low sulfur content fuel legislation is being established in Brazil as a result of new legislation of the Program to Control Vehicular Air Pollution (PROCONVE, in Portuguese), which requires exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) aftertreatment systems implementation in new heavy-duty engines, starting in 1 January 2012, which is equivalent to the Euro V European emission standards to heavy-duty diesel engines. In the United States, a similar standard emission (EPA-07) was adopted in 2007 by the federal regulation 40 CFR 86.007-11. The current emission standards are established by the EPA-13 similar to EURO VI. Countries like China, India and Russia do not adopt the EURO V emission standards yet, with prediction of implementation in 2016–2017 (Cummins Emissions Solutions, 2013).

Diesel engine exhaust emissions consist mainly of high levels of nitrogen oxides (NO_x), and its emission into the atmosphere is one of the main threats to the environment, and as such, meaningful researches on reducing NO_x emissions in diesel engines have been carried out (U.S. Environmental Protection Agency, 1999; Alkemade and Schumann, 2006; Furfori et al., 2010; Miquel et al., 2010). Exhaust gas after combustion control is a reduction strategy, the selective catalytic reduction using urea as reducing agent—the urea-SCR system—is a well-established technique to NO_x reduction of stationary diesel engines (Koebel et al., 2000). According to Hu et al. (2009), of all the strategies developed for heavy-duty vehicles, urea-SCR is one of the most promising.

Diesel engines exhaust gases pose a health concern due to associations with cancer and non-cancer risk effects, and their limits have become increasingly stringent. Pollutant emission concentrations depend on the fuel, engine type, emission control technology, engine age and maintenance, among other factors. Hence, improvements are needed to meet emission standards that regulate pollutants (Hu et al., 2009; Cheng et al., 2008; Chin et al., 2012). As such, the use of alternative fuels as substitutes to fossil fuels has been widely investigated (Bermúdez et al., 2011; Karavalakis et al., 2011; Bakeas et al., 2011; Demirbas, 2011). The biodiesel, an ester-based fuel obtained from vegetable oil, seems to be a promising alternative, as it can be used in diesel engines without modifications. It reduces qualitatively and quantitatively emission of several pollutants that contaminate the environment, and it is a renewable biodegradable source of energy (Turrio-Baldassarri et al., 2004; Lobo et al., 2011). While designed to reduce emissions and comply with emission standards, biodiesel use in conjunction with emission control systems can change the composition and toxicity of exhaust emissions and may increase NO_x emissions (Chin et al., 2012).

In response to health concerns, it is now well known that environmental contamination affects health; the World Health Organization estimates that 2.4 million people die from causes associated with air pollution every year. Achieving strategies to reduce air pollution is of paramount importance benefiting human health. The USEPA, for example, proposed that employing measures to reduce emissions from diesel engines could result in 12,000 fewer mortalities and prevent 15,000 heart attacks and 8,900 hospital admissions in the United States each year (Sierra-Vargas and Teran, 2012). According to Malmqvist et al. (2013), statistically significant associations between NO_x exposure near high-traffic roads and gestational diabetes and preeclampsia were observed in a population exposed to air pollution at levels below current air quality guidelines (NO_2 annual average $<40\ \mu g/m^3$) (WHO, 2005).

On the issue of global warming, nitrous oxide (N_2O) has received great attention because it is a powerful greenhouse gas with its current concentration of 319 ppb in the atmosphere, which can persist for up to 150 years and has global warming potential 298 times than that of CO_2 (Wang et al., 2012).

The prime source of anthropogenic N_2O is agriculture, but some concern may arise due to new diesel exhaust aftertreatment systems, for example, as the chemical reactions in urea-SCR system can produce N_2O (Koebel et al., 2000; Majewski, 2005; Nova et al., 2009).

N_2O emissions from vehicles for the United States in 2001 represented 3% of the greenhouse gases contribution from mobile sources and 1% of the net greenhouse gases contribution from all anthropogenic sources (U.S. Environmental Protection Agency, 2003).

The SCR system with the urea solution has been tested in diesel engines before being mandatory, and a variety of studies of its performance due to catalysts difference were reported (Furfori et al., 2010; Miquel et al., 2010; Nova et al., 2009; Koebel et al., 2002). However, only limited information exists to SCR aftertreatment system vis-à-vis exhaust gases and health risks.

This study is focused on exhaust emission gases and health risk estimates. The main goal is to infer NO_x, NO_2, NO, NH_3 and N_2O exhaust emission data of a Euro V engine equipped with the SCR aftertreatment system, presenting differences among low-sulfur diesel, ultra-low sulfur diesel and soybean biodiesel blended (20% on ultra-low sulfur diesel), referred as LSD, ULSD and B20, respectively. Based on our results, we performed each compound AERMOD model (American Meteorology Society, Environmental Protection Agency, Regulatory Model) dispersion simulation to the City of Curitiba, Parana, Brazil, express bus fleet during summer and winter season. Cancer and non-cancer hazards due to the application of various fuels and engine aftertreatment technologies were also evaluated using the Risk Assessment Information System (RAIS).

While single engine dynamometer emissions testing has limited ability to capture the full range of emissions from an in-use vehicular fleet, dynamometers, nevertheless, offer an inherently high degree of reproducibility and control. In this study, we use data obtained from an engine dynamometer (AVL) following the European Steady Cycle (ESC) testing cycle to simulate the dispersion of the measured pollutants at busy cross-road zones.

To the author's knowledge, there is a few data in the open literature regarding real-world emissions and health impacts of a Euro V engine equipped with an SCR aftertreatment system.

In this context, these results are important in evaluating the aftertreatment technologies and to confirm whether biofuels bring alternative fuel technologies more beneficial to human health and the environment.

2. Materials and methods

2.1. Heavy-duty emission test system

The emission data were sampled in an engine dynamometer drive cycle using low-sulfur (less than 50 ppm) and ultra-low sulfur diesel (less than 10 ppm) and a blend of 20% soybean biodiesel in the laboratory of vehicular emissions. An ESC cycle test in accordance to the Directive 1999/96/EC of the European Parliament and the Directive of the 13 December 1999 Council was considered. The ESC cycle test aggregates set of gas and particulate emission compounds emitted by the engine being tested in a sequence of 13 steady-state modes. The ESC test cycle (Directive 1999/96/EC) was designed to run on high average load factors and to yield very high exhaust gas temperatures (Ericsson, 2001; Mock et al., 2012). Sixty-five percent of the calculated emission responds to load and engine speed above 50%. That is conservative and captures most of the stop-and-go conditions of the drive cycle experienced by urban busses in rush hours. The Brazilian standard regarding the analysis and determination of exhaust gas according to the three-test cycle is the Brazilian Association of Technical Standards