Exposure assessment of particulates originating from diesel and CNG fuelled engines

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1 Introduction

Particulates emitted from combustion engines have been a great concern in past years due to their adverse health effects, such as pulmonary and cardiovascular diseases, morbidity and mortality (Donaldson et al. 2001). The source of particulates can be stationary and transient, such as gas and oil fuelled engines, turbines and boilers (Cohen and Nikula 1999, Kittelson et al. 2002).

Particulate matter (PM) dispersed into ambient air can be classified in many ways: the mechanism of the formation, the size and the composition. (Vallius 2005) Fine particles (PM2.5) are particles with an aerodynamic diameter less than 2.5 μm and particles, greater than 2.5 μm in diameter are generally referred to as coarse particles (PM10). PM2.5 is also called the respirable fraction, because they can penetrate to the unciliated regions of the lung. Fine particles consist of so called ultrafine particles (an aerodynamic diameter less than 0.1 μm). (Brunekreef and Holgate 2002, Penttinen 2004) The sizes of particulates emitted from combustion processes range between 10 nm and 100 μm, and are usually a mixture of unburned and partially burned hydrocarbons. Diesel exhaust particles have a mass median diameter of 0.05–1.0 μm. They are a complex mixture of elemental carbon, a variety of hydrocarbons, sulphur compounds, and other species (Burtscher 2005). They consist of a numerous spherical primary particles, which are agglomerated into aggregates (Amann and Siegla 1982). Particles from natural gas engine emissions range from 0.01–0.7 μm.

Increase in PM10 pollution has been found to be associated with a range of adverse health effects, such as increased use of medication for asthma, attacks of asthma in patients with pre-existing asthma, attacks of chronic obstructive pulmonary disease (COPD), deaths from respiratory causes, admission to hospital for cardiovascular causes, deaths from heart attacks and deaths from strokes (Donaldson et al. 2001).

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While it is unknown, which particulate matter component is the most hazardous for humans, a number of factors suggest that ultrafine particles may be more toxic than larger particles. Ultrafine particles have a large surface area per given mass, and the surface may be able to act as a catalyst for specific reactions with cells or as a carrier for co-pollutants. They also penetrate deeper into the lungs. (Oberdörster 2001) Hydrocarbons, as lipid soluble compounds, can also penetrate the cell membranes of the lung cells, enter into the blood circulation and influence the whole organ system, even reach the brain (Oberdörster et al. 2004).

2 Objectives of the research

The aim of this study was to compare children's exposure to diesel and compressed natural gas (CNG) exhaust particulates, which have been formed and then distributed into the human lung. Particulate measurements were carried out in the Technical Research Centre of Finland for two Euro 2 diesel buses with an oxidation catalyst on one and a partial-DPF catalyst on the other vehicle (DI-OC and DI-pDPF, respectively), and one Euro 3 natural gas bus with an oxidation catalyst on the vehicle (CNG-OC). For the evaluation of particulate emissions in an urban bus route the Braunschweig City Driving Cycle, a transient chassis dynamometer test cycle was used. Particulate number size distributions were measured using an Electric Low Pressure Impactor (ELPI) instrument (Dekati Ltd, Finland) with the size range of 7 nm to 10 µm. The ELPI measurement system yields particulate number concentrations in 12 non-overlapping size bins covering the whole measurement size range.

Estimation of deposited particles into human lung system was computed with a lung deposition model based on a ICRP 66 lung deposition model published by the International Commission on Radiological Protection (ICRP) (ICRP 1994), and it has been used e.g. in Voutilainen et al. (2004). The model includes specific information related to the subjects (including age, ventilation rate, breathing pattern, gender). The respiratory tract is divided into five main deposition regions: the anterior nasal region (ET1), the main extra thoracic region (ET2, including the posterior nasal region, mouth, pharynx and larynx), the bronchial region (BB, consisting of the trachea and bronchi), the bronchiolar region (bb, consisting of the bronchioles), and the alveolar interstitial region (AI, consisting of the alveolar ducts and sacks) (ICRP 1994). Exposure time was chosen to be the same as in the Braunschweig City Driving Cycle, i.e. 1740 s. Physiological parameters were standardized by a "virtual human", a 10-year old school child. Children are more vulnerable to air pollution than adults, because of higher metabolism per body weight and they are often more active during the day. Also airways and lung function in children are under development and therefore toxic substances may cause permanent impairments of the respiratory system. The chosen activity levels were sleeping, sitting, light exercise and heavy exercise. Exposure to particulates is assumed to correspond to what comes out from an exhaust pipe. The dilution of the exhaust gas and the transformation of particulates in the ambient air are ignored. However, there is a recent study (Rönkkö et al. 2006) where the researchers found that on-road and laboratory particulate measurements produce repeatable results for geometric mean diameters of nucleation and accumulation mode particulates.

3 Results

3.1 Particulate measurements

Measured particulate number size distributions are presented in Figure 1.

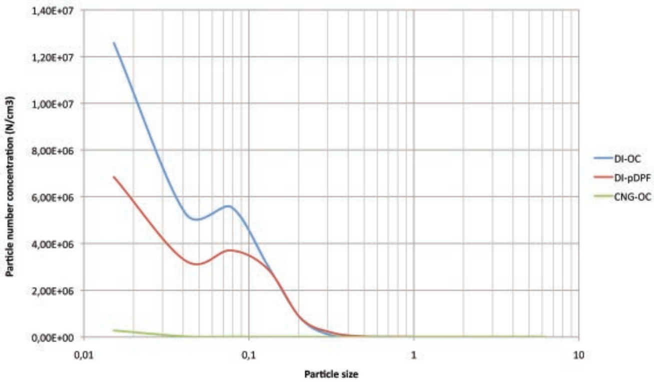

Figure 1 Measured diesel and CNG particulate number concentrations from Euro 2 diesel city bus with DOC or pDPF catalyst and Euro 3 CNG city bus with OC catalyst during Braunschweig City Driving Cycle.

The highest particulate levels were measured for the Euro 2 diesel bus with an oxidation catalyst, and almost the same levels were detected for the Euro 2 diesel bus with a partial-DPF catalyst. Particulate levels of the Euro 3 gas bus were significantly lower. There were only minor differences between the shapes of the particulate size distributions of different engines. For all engines the highest count mode seems to be for particulates smaller than 50 nm, which represents the nucleation mode. Most of the particulates emitted from these engines are so small (< 2.5 μm) that they can penetrate into the unciliated regions and to the gas-exchange region of the lung.

3.2 Lung deposition model

Results showed that the inhaled doses of particulates differed according the used after-treatment methods and fuel and were highest, when using the OC in diesel bus. 8% of all inhaled diesel particulates stayed in lungs during the time of sleeping, 9–10% in sitting, 27–30 % in light exercise and 45–50 % in heavy exercise. 11% of all inhaled CNG particulates stayed in lungs during the time of sleeping, 14% in sitting, 41% in light exercise and 71% in heavy exercise. The rest of inhaled particulates come out from the respiratory system by exhalation and clearance effects (coughing, wiping and swallowing). The deposition of particulates depends also on the way of breathing: nose or mouth breathing and the intensity of breathing (Tenhola and Jantunen 1999).

The most deposited diesel and CNG particulates penetrate deep into the unciliated regions and gas-exchange region of the lungs of a 10-year-old school child. Percentages of all deposited particulates in the alveolar-interstitial region for a DI-pDPF, a DI-OC or a CNG-OC were 53.5%, 52.9% and 49.6% accordingly, in sleeping, 55.7%, 55.2 % and 52.3 % in sitting, 66.0%, 65.9% and 64.8 % in light exercise, and 70.4%, 70.4% and 70.1% in heavy exercise (Figure 2).

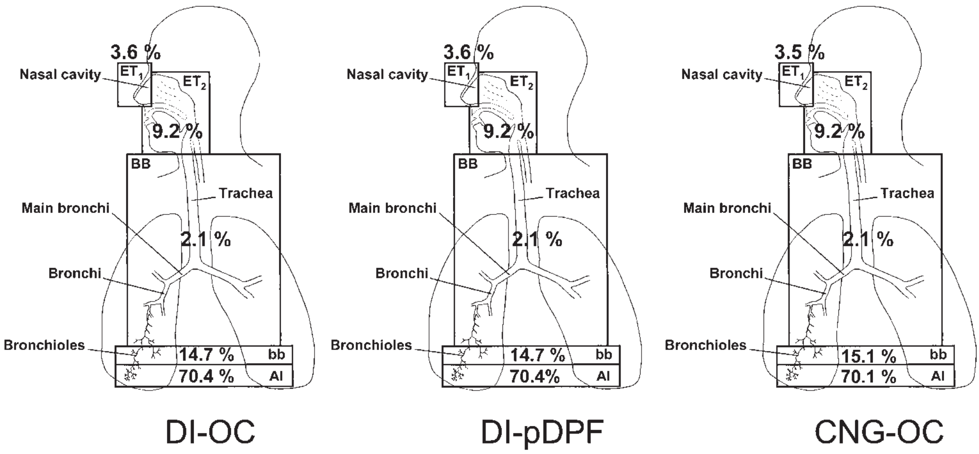

Figure 2 Percentages of deposited diesel and CNG particles for each region of the lung. (DI-OC = Euro 2 diesel bus with an oxidation catalyst, DI-pDPF = Euro 2 diesel bus with a partial-DPF catalyst, CNG-OC = Euro 3 natural gas bus with an oxidation catalyst, ET1 = anterior nose, ET2 = main extrathoracic region, BB = bronchial region, bb = bronchiolar region, and AI = alveolar interstitial region)

The total exposure in numbers to particulates originating from diesel fuelled engines DI-OC and DI-pDPF was more than 60- and 35-fold in all activity levels, respectively, compared to the exposure to particulates originating from the CNG fuelled engine (Figure 3). The highest amounts of diesel particulates deposited in the child's lungs during heavy exercise. The deposition increased more than six-fold during the rest to heavy exercise and three-fold to light exercise as compared the rest. Due to the difference in the deposited amount of particles, the health risk to a 10-year-old school child seems to be different depending on the after-treatment method and fuel used in busses.

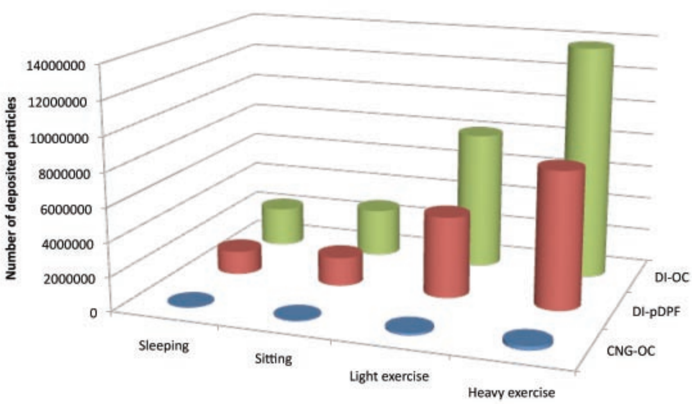

Figure 3 Number of diesel and CNG particulates deposited into respiratory system of a 10-year old child during different breathing conditions. DI-OC = Euro 2 diesel bus with an oxidation catalyst, DI-pDPF = Euro 2 diesel bus with a partial-DPF catalyst, CNG-OC = Euro 3 natural gas bus with an oxidation catalyst

4 Relevance of the research

This study creates new knowledge about fine particulate deposition into human respiratory system. It increases understanding of chemical and physical properties of particulates formed in diesel and gas engines as well as exposure and lung deposition of these particulates. Information of the particulate properties and results from the exposure assessment studies of diesel and CNG particulates can be directly used when developing new abatement techniques for the particle emissions.

The kinds of lung deposition models used in this study are also usable in risk assessment. Using models is also significant also from the ethical point of view.

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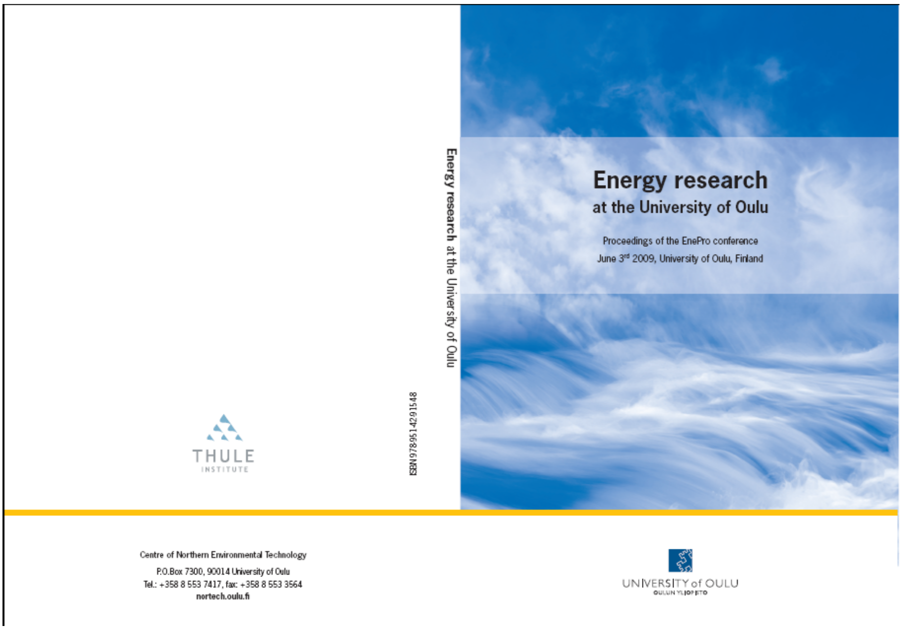

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