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Combustion particles emitted during church services: Implications for human respiratory health

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ABSTRACT

Burning candles and incense generate particulate matter (PM) that produces poor indoor air quality and may cause human pulmonary problems. This study physically characterised combustion particles collected in a church during services. In addition, the emissions from five types of candles and two types of incense were investigated using a combustion chamber. The plasmid scission assay was used to determine the oxidative capacities of these church particles. The corresponding risk factor (CRf) was derived from the emission factor (Ef) and the oxidative DNA damage, and used to evaluate the relative respiratory exposure risks. Real-time PM measurements in the church during candle–incense burning services showed that the levels (91.6 μg/m^3 for PM_{10}; 38.9 μg/m^3 for $PM_{2.5}$) exceeded the European Union (EU) air quality guidelines. The combustion chamber testing, using the same environmental conditions, showed that the incense Ef for both PM_{10} (490.6–587.9 mg/g) and $PM_{2.5}$ (290.1–417.2 mg/g) exceeded that of candles; particularly the $PM_{2.5}$ emissions. These CRf results suggested that the exposure to significant amounts of incense PM could result in a higher risk of oxidative DNA adducts (27.4–32.8 times) than tobacco PM. The generation and subsequent inhalation of PM during church activities may therefore pose significant risks in terms of respiratory health effects.

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1. Introduction

Particulate matter (PM), generated during combustion processes and occurring in fine and ultrafine size fractions, is a common component of indoor air (BéruBé et al., 2004). Human respiratory exposure to these microscopic particles has been linked to the formation of oxidative stress, DNA adducts and respiratory diseases (Bérubé et al., 2007). Many epidemiological studies have linked outdoor air pollution to mortality and morbidity (Dominici et al., 2006), however, people spend approximately 87% of their time indoors (BéruBé et al., 2004) in both private and public buildings. Clinical studies have demonstrated that exposure to high PM concentrations causes irreversible damage in the respiratory system (Stinn et al., 2005). Human behaviour involving combustion, such as smoking, candle and incense burning, results in the rapid generation of significant amounts of ultrafine particles (UFPs), which can pass through to the distal respiratory system with resultant initiation of cardiopulmonary diseases (Steinvil et al., 2008).

The dominant religion in the UK, comprising approximately 53% of the adult population, is Christianity (Tearfund, 2007). It is reported that on average 4.9 million people make weekly visits to church, and additionally, 3.9 million and 5.7 million attended church during Easter and Christmas, respectively (Tearfund, 2007). Candles and incense are commonly used during church services, generating PM and resulting in poor indoor air quality (Loupa et al., 2010). This is especially the case for the ultrafine sized fractions (Pagels et al., 2009).

Combustion chambers, with controlled humidity and temperature, have been used for the quantification and collection of PM (Pagels et al., 2009). The results have shown that particle emissions from candles and incense varied, and they depended both on their pre-combustion composition and the combustion conditions (Pagels et al., 2009; Yang et al., 2007). The main PM type released from candles was nano-soot particles, whereas incense particles consisted of nano-soot, micro-soot, mineral and organic particles (Chuang et al., 2011; Pagels et al., 2009). The primary soot nanoparticles had a tendency to agglomerate into larger soot nano-structured particles with chain and cluster morphologies; controlled by parameters such as particle concentrations, humidity and temperature (Liu et al., 2003). In addition, other components of candles and incense, such as wicks, colour pigments and fragrant smelling chemicals, contained metals and organics that were able to condense onto the surfaces of the primary particles by nucleation (Tissari et al., 2007, 2008).

The capacity of PM to cause oxidative DNA damage by free radicals was assessed. The acellular plasmid scission assay (PSA) is an established method of analysing different types of PM such as indoor PM (Shao et al., 2007). The principle of this assay is that free radicals generated from particles can convert the supercoiled, undamaged, isoform plasmids to relaxed and linear isoforms (Shao et al., 2007).

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This change in quaternary structure alters their electrophoretic mobility, thus enabling separation and quantitation on a gel.

Influenced by the physicochemical characteristics, free radical generation by combustion-derived PM is the primary source of oxidative stress, potentially resulting in cell dysfunction, inflammation and PM-related diseases (Donaldson et al., 2005). DNA is believed to be a critical target for PM-related reactive oxygen species (ROS), and potentially associated with the development of inflammatory lung diseases, including cancer (Danielsen et al., 2009).

Our previous study determined that physicochemistry was related to bioreactivity, leading to oxidative DNA damage (Shao et al., 2007). Moreover, few studies have assessed their respiratory exposure risk during church activities. An electrical low pressure impactor (ELPI) was used for particle collection and gravimetric measurements. Field emission scanning electron microscopy (FE-SEM) was used to investigate the morphology of particles collected from ELPI substrates and swabbed from the church walls. To determine oxidative DNA damage caused by particulate bioreactivity, the PSA was employed. For both the church and test chamber, an exposure assessment was undertaken, and subsequently linked to their oxidative capacities.

2. Materials and methods

2.1. Measurement site

Particle collection and measurement were conducted during the Easter holiday (3rd–6th April, 2010) in a church located approximately 8 km north-west of Cardiff city centre (Wales, UK): the background in this area was suburban and had minor vehicle traffic activities. The corresponding outdoor PM data during this sampling period was obtained from the Department for the UK Air Quality Archive (Defra, 2010).

The church used for sample collection (total volume of 885 m^3; Fig. 1) comprised an entrance room, one congregation area, two altar areas, one preparation room and one storage room. During the sampling campaign, the preparation and storage rooms were closed with a 1 cm gap under the door. All the church windows were locked. The ventilation system used in this church was positioned on the roof

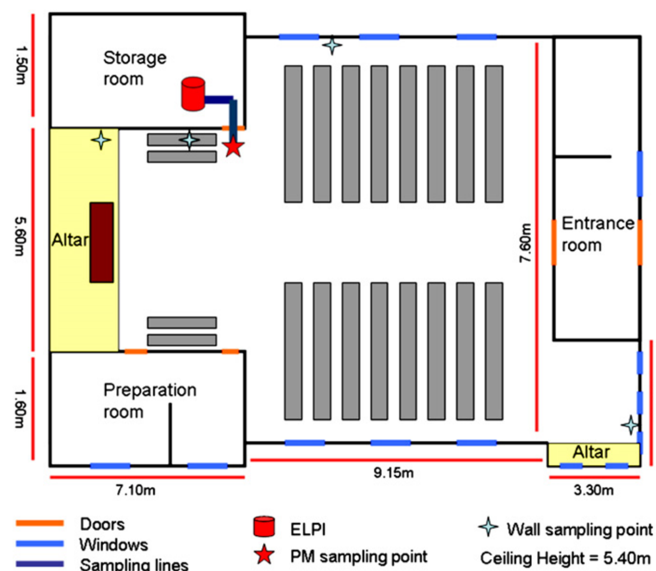

Fig. 1. Illustration of the sampling locations in the church. One entrance room, one congregation area, two altar areas, one preparation room and one storage room for a total volume of 885 m^3. The ELPI was positioned in the storage room with an extended tube to the congregation areas (red star). The wall wiped samples were taken from the main area and the two altar areas at 1.5 m above ground level (blue star).

(5.4 m in height from the ground). The ELPI used for PM measurements and collection (Dekati Ltd, Finland) was set up in the storage room and connected with an extended tube to the congregation area (approximately 1 m above ground level, and 7 m to the main altar area). Most of the burning activities were performed in the altar areas. All church activities during the study periods, such as cleaning and the switching on/off of the heater, were logged by the church staff.

2.2. Chamber measurements

The burning of four types of candles (C1–C4), one oil candle (O1), one charcoal base (for incense burning; CH1) and two types of incense (0.1 g of resins; I1–I2) was performed inside a polyvinyl chloride combustion chamber (volume 0.0495 m^3; Fig. S1) in a dedicated fume cupboard located in a laboratory at the School of Biosciences (Cardiff University). The incoming air, average temperature and humidity of 22 °C and 53% respectively, was passed through a high efficiency particulate air (HEPA) filter, and directed into the chamber at a constant flow rate of 6 l/min. The resultant smoke was mixed by a fan inside the chamber and was introduced into the secondary dilution chamber, mixing with 24 l/min of HEPA-filtered air. The ELPI was used to measure and collect the diluted particulate smoke.

2.3. ELPI

The ELPI was used to size PM ranging between 0.007 μm and 10 μm mean diameter by 12 inertial-based cascade impactors (Price et al., 2010). The particles were collected onto 25 mm aluminium foil substrates at a consistent flow rate of 30 l/min after zeroing. A fast mobility particle sizer (FMPS; Mode 3091, TSI Inc., USA) and an aerodynamic particle sizer (APS; Mode 3321, TSI Inc., USA) were both used to calibrate the ELPI ranging 0.0056–0.56 μm and 0.5–20 μm, respectively. The measurement mode was set at 400,000 fA current range with a particle density of 1 g/cm^3 (Sander et al., 2011). Grease was not coated onto the foil substrates (the recommended method of eliminating particle 'bounce-off') in order to reduce contamination. The organic particles produced by candle–incense burning were 'sticky' and the amount of 'bounce-off' during the collection is believed to be insignificant. All samples were kept at 4 °C prior to further analyses.

2.4. PM sampling from the church walls

Particles adhering to the church walls were swabbed onto 47 mm glass microfibre filters (2 μm pores; Whatman, UK). The sampling spots were chosen in the main congregation area and the two altar areas at 1.5 m above ground level (respiratory zones; Fig. 1).

2.5. FE-SEM

FE-SEM (Philips Electron Optics, NL) was undertaken on the ELPI and wall-swabbed samples using the methods previously described (BéruBé et al., 1999). Briefly, the filters were mounted onto aluminium SEM stubs (13 mm; Agar, UK), then imaged by FE-SEM at an accelerating voltage of 25 kV, spot size 3.

2.6. Determination of oxidative DNA damage

The PSA has been commonly used as an *in vitro* marker for the oxidative capacities of PM (Shao et al., 2007). PM samples extracted from the ELPI substrates were diluted with molecular grade water (Sigma-Aldrich, UK) to 250 μg/ml (n = 9). The PSA is described in detail in previous studies (Shao et al., 2007). The samples were run with negative controls (molecular water; 5% damage) and positive controls (a restriction enzyme, Pst I; 100% damage).

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