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Impact of the wood combustion in an open fireplace on the air quality of a living room: Estimation of the respirable fraction

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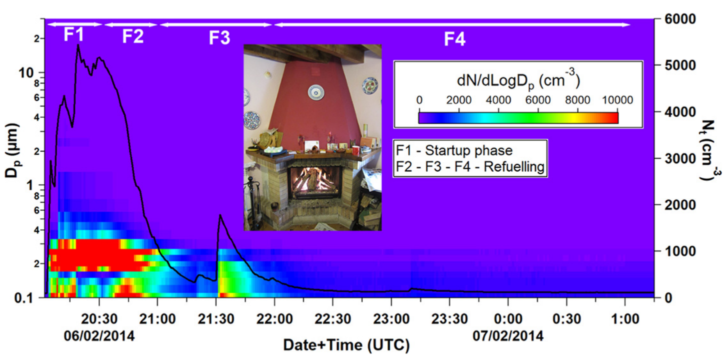
HIGHLIGHTS

- Combustion in the fireplace emissions up to indoor concentrations of 5500 fine particles cm^{-3}
- The ignition and first refueling emit more and larger particles than later refueling.
- Incorrect cleaning of the fireplace can be as polluting as the refueling processes.
- The ash removal process can be very dangerous at the pulmonary level.

GRAPHICAL ABSTRACT



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ABSTRACT

Presently, both in rural areas and in cities open fireplaces are still present and large quantities of wood are combusted every year. The present study aims to characterize aerosol size distribution, chemical composition and deposition in the human respiratory tract of particles emitted during the combustion of logs of oak in an open fireplace installed in the living room of a typical village house. CO_2 and CO levels and aerosol size distribution have been continuously monitored and a PM_{10} sampler with two types of filters for chemical and microscopic analysis was also installed. The increment, between the operating periods and the indoor background, in the organic carbon and PM_{10} concentration due to the use of the fireplace is 15.7 ± 0.6 (mean ± standard deviation) and 58.5 ± 6.2 μg m^{-3}, respectively. The two main polluting processes during the operation of the fireplace are the ignition with the subsequent refueling and the final cleaning of the residual ashes. In both phases mean values around 1800 particles cm^{-3} with CMD of 0.15 μm were measured. However, while PM_{10} levels of 130 ± 120 μg m^{-3} were estimated for the ignition stage, values of 200 ± 200 μg m^{-3} were obtained during the final cleaning step. Assessment conducted according to ISO standard 7708:1995, demonstrated that a person who stays in a living room when an open fireplace is lit will inhale, on average, 217 μg m^{-3} and 283 μg m^{-3} during the ignition and the refueling stages, respectively. Subsequent refueling proved to be much less polluting. The ashes removal can also be very polluting and dangerous to health if there are hidden small incandescent embers among the ashes (estimated PM_{10} of 132 μg m^{-3}), reaching a CO_2 level of 1940 ppm and a dangerous level of CO of 132 ppm.

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1. Introduction

Nowadays air quality constitutes an important public issue, due to the wide variety of impacts linked to atmospheric pollution (on climate, public health, ecosystems, visibility, etc.) (Bell et al., 2017; Thurston, 2017; Shi et al., 2014; Skouloudis and Kassomenos, 2014; Calvo et al., 2013). A recent report published by UNICEF (2016) attributes around 600,000 deaths each year in children under 5 years of age to indoor and outdoor air pollution, mainly in poor countries. Residential wood combustion (RWC) constitutes a major source of air pollution both outdoors and indoors. In Europe, RWC is becoming increasingly more widespread due to i) the rising prices of fossil fuels; ii) wood is a renewable energy and iii) the establishment of climate change mitigation measurements (Denier van der Gon et al., 2015). In contrast, this practice has been identified as the major contributor to local indoor/outdoor air pollution in Europe during winter months (Amato et al., 2016; Evtyugina et al., 2014; Gonçalves et al., 2012; Bari et al., 2010; Caseiro et al., 2009; Puxbaum et al., 2007).

The characterization of emissions from biomass burning is not an easy task, as there are many influencing factors, such as stove design, operating and combustion conditions, species of wood and their characteristics, ignition technique, way of cutting and splitting the firewood (Vicente et al., 2015; Calvo et al., 2014; Alves et al., 2011; Tissari et al., 2007).

Incomplete combustion is one of the main problems that largely contribute to the emission levels of residential appliances. Particulate matter emitted during RWC under poor combustion conditions is mainly composed of carbonaceous compounds, mostly organic carbon (OC) and smaller amounts of elemental carbon (EC) (Tissari et al., 2008). High CO indoor levels are also linked to this poor combustion conditions and pointed out to be responsible for several annual deaths from poisoning. When an efficient combustion takes place, aerosols are mainly constituted by ash related material (Torvela et al., 2014) and CO is completely oxidized to CO_2.

When focusing on particulate matter emissions, it is essential to evaluate not only the chemical composition, but also its size distribution. The particle aerodynamic diameter is of critical importance in assessing the health impacts, since the transport and deposition on the different zones of the respiratory tract depends on it (Castro et al., 2015; Donaldson et al., 2000). Particles smaller than 2.5 μm, and especially those smaller than 1 μm, deserve greater attention, given that they constitute the highest health risk as they reach the alveoli (Dockery, 2001; Pope, 2000). This fact is particularly relevant when emissions from RWC are evaluated, as they lie mainly within this submicrometer interval (Hosseini et al., 2010). Numerous health problems derived from the exposure to RWC emission (cardiovascular effects, decreased lung function, increased severity/incidences of acute asthma, reduced resistance to infections, etc.) have been addressed in several studies (Tapanainen et al., 2012; Bølling et al., 2009; Naeher et al., 2007). Some of them have focused on the mutagenic effects related to these emissions (Canha et al., 2016; Vu et al., 2012).

In many European countries with long cold periods it is usual to light the fireplace during several months of the year. Johansson et al. (2008) have compiled a wide use of fireplaces in Europe and in the rest of the world. Tissari (2008) has also shown that the combustion of residential wood is a major source of fine particles in Europe. Fireplaces are usually installed in the living room of many single-family dwellings, both in rural areas and in cities. Large amounts of wood are combusted in these domestic devices every year. Most studies have focused on evaluating the outdoor emissions caused by wood burning in open fireplaces, and only a few have analyzed the impact on indoor air quality (Pettersson et al., 2011; Noonan et al., 2012; Chowdhury et al., 2013; McNamara et al., 2013; Canha et al., 2014; Salthammer et al., 2014; Hanoune and Carteret, 2015). Furthermore, the majority of these studies do not encompass particle size distributions and only a few articles focus on the impact on the respiratory tract. However, these aspects should be a cause of concern during the coldest months when people spend hours on end breathing polluted indoor air.

The objectives of the present study are:

- To characterize the aerosol chemical composition and size distributions in indoor air over the different combustion stages of logs of a common Southern and mid-European wood (*Quercus pyrenaica* – Pyrenean oak–) in an open fireplace.
- To compare the different phases of the combustion process and the cleaning steps (ash removal with ashes and hot embers or only cold ashes).
- To estimate the deposition in the human respiratory tract through the inhalable, thoracic, tracheobronchial and respirable fractions according to the *ISO (1995)* standard for healthy adults and high risk people (children, frail or sick people).
- To suggest appropriate control strategies to minimize the adverse health effects.

This type of study is of great importance in the establishment of mitigation measures for improving indoor air quality during wood combustion in domestic appliances.

2. Methodology

2.1. Sampling location

Ten wood combustion experiments were carried out using a traditional Spanish brick open fireplace operated manually in batch mode and with no control of combustion air. The fireplace is characterized by a combustion chamber with a volume of 0.09 m^3, corresponding to 0.35 m height, with a trapezoidal base of 0.52 and 0.63 m width and 0.45 m depth. This combustion device is installed in the 41 m^3 living room (5.97 m length, 3.17 m width, 2.17 m height) of a typical village house in Báscones de Valdivia (Palencia, Spain, Fig. S1), located at 42° 45′ 57″ N, 4° 11′ 5″ W and 912 m above sea level. This town has a population of 20 inhabitants (National Statistics Institute, 2013).

2.2. Sampling and analytical equipment

2.2.1. Aerosol characterization

The sampling instruments were placed at 1.1 m height on a table, at nose level, in order to quantify the particles inhaled by people sitting in the living room. In order to obtain a complete physico-chemical characterization of aerosols emitted to the living room during the combustion experiments, two different instruments were used for particle sampling:

a) Gent sampler.

A Gent PM_{10} stacked filter unit sampler was equipped with quartz filters for later chemical analyses. In two of the ten combustion experiments, polycarbonate filters (0.2 μm pore size) were used for a later morphological and elemental composition analysis of individual aerosol particles by field emission scanning electron microscopy (FE-SEM). After PM_{10} mass determination by gravimetry, small punches from the loaded quartz filters were analyzed by two different techniques: i) a thermal-optical transmission technique for organic and elemental carbon determination (Pio et al., 2011), and ii) ICP-MS and ICP-AES analysis for trace and major elements (Querol et al., 2001).

b) Optical spectrometer:

A laser spectrometer probe (the Passive Cavity Aerosol Spectrometer Probe, PMS Model PCASP-X) was continuously monitoring and sorting