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Indoor aerosol size distributions in a gymnasium

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HIGHLIGHTS

- In the indoor environment of a gym PM_{10} concentrations are highly variable.
- Sports activities, occupancy rates and cleaning are important factors to PM.
- Sports activities lead to the resuspension of particles from the surfaces.
- The use of magnesia alba contributes to an indoor air with many particles >1 μm.
- The maximum respirable fractions could reach values like those found in industry.

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ABSTRACT

In this study, an indoor/outdoor monitoring program was carried out in a gymnasium at the University of Leon, Spain. The main goal was a characterization of aerosol size distributions in a university gymnasium under different conditions and sports activities (with and without magnesia alba) and the study of the mass fraction deposited in each of the parts of the respiratory tract. The aerosol particles were measured in 31 discrete channels (size ranges) using a laser spectrometer probe. Aerosol size distributions were studied under different conditions: i) before sports activities, ii) activities without using magnesia alba, iii) activities using magnesia alba, iv) cleaning procedures, and v) outdoors. The aerosol refractive index and density indoors were estimated from the aerosol composition: 1.577–0.003i and 2.055 g cm^{-3}, respectively. Using the estimated density, the mass concentration was calculated, and the evolution of PM_1, $PM_{2.5}$ and PM_{10} for different activities was assessed. The quality of the air in the gymnasium was strongly influenced by the use of magnesia alba ($MgCO_3$) and the number of gymnasts who were training. Due to the climbing chalk and the constant process of resuspension, average PM_{10} concentrations of over 440 μg m^{-3} were reached. The maximum daily concentrations ranged from 500 to 900 μg m^{-3}. Particle size determines the place in the respiratory tract where the deposition occurs. For this reason, the inhalable, thoracic, tracheobronchial and respirable fractions were assessed for healthy adults and high risk people, according to international standards. The estimations show that, for healthy adults, up to 300 μg m^{-3} can be retained by the trachea and bronchi, and 130 μg m^{-3} may reach the alveolar region. The different physical activities and the attendance rates in the sports facility have a significant influence on the concentration and size distributions observed.

1. Introduction

Different studies have pointed out the importance of evaluating and controlling indoor particulate matter levels (Halios and Helmis, 2007; Hussein et al., 2015; Oh et al., 2014; Owen et al., 1992; Wolkoff, 2013; Žitnik et al., 2010). This is due to the fact that, nowadays, people spend more than 90% of their time indoors. Homes, schools/universities, work and entertainment places are among the most common indoor spaces (Massey et al., 2012; Salma et al., 2013; Wolkoff, 2013). Sports facilities arouse particular interest in the study of indoor air quality (IAQ), due to the contrast between the aim of physical fitness and the risk of respiratory problems associated with the practice of sports. One important aspect linked to sports activities is the increase of ventilation rates in athletes and other sportspeople, and the subsequent increase in the amount of pollutants drawn into the lungs (Daigle et al., 2003). Children

Abbreviations: BC, black carbon; CMD, Count Median Diameter; IAQ, indoor air quality; PCASP, Passive Cavity Aerosol Spectrometer Probe; PM, particulate matter; POM, particulate organic matter; SMD, surface mean diameter; TSP, total suspended particle; VMD, volume mean diameter; VOCs, volatile organic compounds.

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are especially susceptible to these health problems because of their higher physical activity, higher metabolic rate and the resultant increase in minute ventilation (Braniš et al., 2009; Chalupa et al., 2004; Gauderman et al., 2004).

The concentration, composition and sources of indoor air pollutants vary considerably from one micro-environment to another (Colbeck and Nasir, 2010; Alves et al., 2013a; Sangiorgi et al., 2013; Batterman et al., 2012). As a consequence, different indoor aerosol size distributions are registered. The study of aerosol size distribution constitutes an essential tool when air quality studies are carried out. It provides information related to the concentration of particles that can be retained on the different zones of the respiratory tract (Donaldson et al., 2000; Kreyling et al., 2006) and, on the other hand, it contributes to knowledge on aerosol sources, formation, and growth mechanisms (Lan et al., 2011). This information is essential when investigating mitigation measures. Generally, the particles that can reach the different zones of the human respiratory tract are classified as: i) particles larger than 10 μm in diameter, which are retained in the extrathoracic region, ii) particles smaller than 10 μm, which may pass into the tracheobronchial region, iii) particles smaller than 2.5 μm which can reach the alveoli and consequently the bloodstream, which may endanger human health (Pope et al., 2002), and iv) particles smaller than 1 μm, which, according to medical studies, are considered the highest health risk (Dockery et al, 1993; Dockery, 2001; Pope, 2000). Important relationships have been pointed out between indoor levels of coarse particles and the number of occupants and activities carried out (Braniš and Šafránek, 2011; Buonanno et al., 2013).

Previous studies have shown the relevance of particulate matter in sports facilities (Alves et al., 2013b, 2014), highlighting the importance of the chemical composition and morphology of aerosols. However, the number of studies on aerosol size distributions is still small. Weinbruch et al. (2012) studied the influence of the different kinds of magnesia alba on the dust concentrations in indoor climbing gyms, including also particle size distributions.

Given the relevant information obtained from this aerosol characteristic, a deeper study of this topic is essential to provide i) a complete characterization of particles, and ii) feasible measures for reducing particles in this kind of facility. As a result, it will be possible to follow healthy habits, such as sports, reducing the risk of respiratory disease.

The objectives of the present study are:

- to characterize the aerosol size distributions in a university gymnasium under different conditions and sports activities (with and without magnesia alba);
- to compare the data with those observed without sports activities and with outdoor measurements; and
- to determine firstly the inhalable and thoracic fractions according to the Spanish standard UNE 77213, equivalent to ISO 7708:199, and then the tracheobronchial and respirable fractions for healthy adults and high risk people (children, frail or sick people).

This study is a useful tool for identifying the main sources of particulate matter in sports facilities such as gymnasiums, as well as for developing appropriate control strategies to minimize the adverse health effect on sportspeople.

This study complements two previous papers already published on the chemical composition and morphology of aerosols in this sports facility (Alves et al., 2013b, 2014).

2. Methodology

2.1. Description of sports facilities

A gymnasium at the University of Leon, Spain, was the sports facility chosen to carry out the monitoring program. The gymnasium is 15 m wide, is 27 m long and has a height of 10.6 m. It has no windows but a horizontal axis half-cylinder skylight (5 m diameter and 20.3 m length) centered on the roof. The vinyl flooring is nearly totally covered by gym mats and safety mattresses. The sports equipments include asymmetric bars/high bar, rings, parallel bars, beams, a pummel horse, a tumble track, trampolines, wall bars, and a dug pit with foam cubes. A side gate was frequently open when the gymnasium was busy, due to the high temperatures reached in summer after the late morning hours. The gym does not have any mechanical ventilation system. Further details have been described in Alves et al. (2013b). During the sampling campaign, it was occupied by college gymnasts between 7:00 and 12:00 (UTC) and between 15:00 and 17:00 (UTC).

2.2. Sampling and measurement equipments

The monitoring campaign was carried out between 15 and 21 July, 2012. The campaign was planned for the duration of a summer activity that lasted a week. Sampling with activities was conducted for five days, while another two days (weekend) were taken as background. Although the sample size was limited by the duration of sports activities, the homogeneity of the inter-daily pattern ensured the repeatability of the activities studied. Sampling could not have been made during the school year because gym activities are different from one day to another, without a temporal pattern, which would make difficult the possibility of reaching robust conclusions.

Several instruments were operating in order to characterize aerosols, gases and comfort parameters in the gymnasium. The results related to gases and environmental conditions (temperature, relative humidity, CO_2, CO and total volatile organic compounds) were presented in Alves et al. (2013b) and the morphology and chemical composition of particles can be found in Alves et al. (2014). This study completes these two previous papers, and presents a complete characterization of aerosol size distributions and its impact on the respiratory tract, under different activities, in this sports facility.

Particle size spectra were measured in 31 discrete channels (size ranges between 0.1 and 10 μm latex particle size) using a laser spectrometer probe (Passive Cavity Aerosol Spectrometer Probe, PMS Model PCASP-X). The principle of this instrument is based on the measurement of the intensity of the light scattered by the particles when passing through a laser light beam (He–Ne, 632.8 nm). The instrument detects single particles and groups them into different channels.

Several corrections need to be made on the number of counts indicated by the spectrometer to determine the exact number of particles per unit of volume sampled in each channel. The value of the sample volume has been adjusted according to the altitude (832 m asl) of the sampling point (Calvo et al., 2010). Similarly, the measurement in each time interval has been corrected by the spectrometer activity. This instrument generally underestimates the true diameter of ambient aerosols and a correction by the refractive index is necessary to bring the particle size distributions measured close to the real ones. The diameters corresponding to the different channels (particle bin sizes) were corrected using the refractive index in a model based on the Mie Theory (developed by Bohren and Huffman, 1983). Thus, the device was calibrated by the manufacturer using polystyrene latex (PSL) particles of a known size. The refractive index of latex beads (1.59–0i) is different from that of atmospheric particles, resulting in an aerosol size distribution that is "PSL size equivalent". In this study the refractive index and density were derived from aerosol composition (Alves et al., 2014), following the methodology by Levin et al. (2010), assuming that PM_{10} constituents are present as particular chemical compounds with a specific density and a typical refractive index. The values obtained were: 1.549–0.025i and 1.577–0.003i, and 1.940 and 2.055 g cm^{-3} outside and inside the gymnasium.

In order to evaluate the influence of the variability in the estimated refractive index on the estimated particle diameters, a sensitivity test was carried out. Fig. 1 shows the variation in the mean particle diameter