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SHORT COMMUNICATION

Low cost air quality monitors to evaluate nanosized particulate matter. A pilot study

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Abstract

Particulate matter is defined as a mixture of airborne solid particles and liquid droplets that can be inhaled and may cause serious health problems. Such elements are currently measured utilizing air quality monitoring devices that provide information on PM 10 and PM 2.5 levels giving information on pollution levels. However, many difficulties are encountered in the determination of nanosized ultra fine particles (UFPs) due to their reduced dimensions. The present paper highlights the ability of low cost air quality monitors to estimate UFPs concentration through a correlation based on the measures of PM 10 and PM 2.5.

Keywords: *Air Quality Detectors; Light Scattering; Nanoparticles; Particulate Matter; Toxicology.*

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INTRODUCTION

Particulate Matter, abbreviated as 'PM', is a mixture of airborne solid particles and liquid droplets that can be inhaled and may cause serious health problems. PM includes both organic and inorganic particles such as dust, pollen, soot and smoke that have different characteristics (e.g. shape, optical properties, size and composition) and that are divided into sub-categories based on the particle aerodynamic size [1-3]. In particular, PM10 have a diameter less or equal then 10 μm and are called thoracic particles. The particles with a range of aerodynamic sizes between 10 and 2.5 μm (PM10-2.5) are known as coarse fraction while those with a diameter less or equal to 2.5 μm are the PM 2.5 or fine fraction [4]. If the aerodynamic size is equal or less than 100 nm, the particles are called ultrafine particles (UFPs), and one of the main sources of this type of primary particles is diesel exhaust (DEP). In this class, the engineered particles with at least one dimension smaller than 0.1 μm, are known as nanoparticles (NPs) [5]. In general, different subsets of components may be found on different PM fractions. For example, PM2.5 comprises the soot fraction and particles grown from the gas phase with subsequent agglomeration, including inorganic ions such as sulfate, nitrate, and ammonia, as well as combustion-form carbon, organic aerosols and metals. PM 10-2.5 is dominated by mechanically abraded or ground particles including finely divided minerals such as aluminium oxides silicate, iron, calcium, and potassium while UFPs are composed of both primary and secondary particulate matters [6]. The primary fraction is the one that is emitted directly from the emission sources (e.g. diesel engines, automobiles and biomass combustion) and often includes agglomerate/aggregates of smaller particles [6] whit size generally in the range between 30 and 100nm [3-4]. The secondary fraction is composed of particulate matter formed in the atmosphere and includes sulfuric acid, sulfates and organic reaction products of low volatility. The size of this fraction is generally in the range between 100 and 200 nm.

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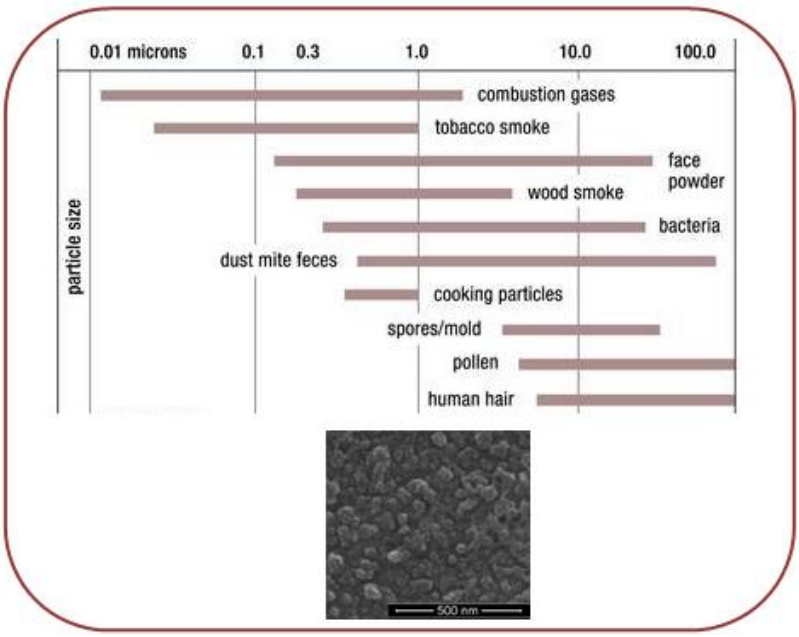

Fig. 1. Size range of common pollutant sources.

Factors affecting PM Toxicology

The role of the size, shape and composition in the biological/toxic effects of particles has been explored by different authors that found evidences on the relation of surface area, reactivity, and components of the particles with their toxicity [5-8]. Then, the characterization of size and physicochemical composition is necessary to understand the toxicology of particles and the determination of size, the dynamics of agglomeration and aggregation, the area and the charge are mandatory for any toxicological evaluation [7]. For example, toxicity of urban particles is related with the determination of total carbon, black carbon, transition metals, nitrates, sulfates, oxidative potential, and polycyclic aromatic hydrocarbons [8]. In addition, other studies focus on the biological components of PM. These biological components are released from plants, soil, solid biofilms or liquid sources to become suspended in the air (e.g. plant pollen, spores, mold, bacteria or microbial metabolites) and play a central role in allergies, intolerances and toxic responses in exposed individuals [9]. For example, after inhalation, the biological components are responsible of the stimulation of alveolar macrophages and respiratory epithelial tissues, releasing proinflammatory cytokines and chemokines. The biological components may also have synergetic effects with other components of the PM, such as diesel exhaust, enhancing IgE production and thus facilitating allergic sensitization [10]. About 1–4% of the total mass of PM10 for urban and rural areas is of biological origin [13-14]. Overall, PM size is the parameter identified by national governments to assess the quality of the air. In particular, the toxic action derives from the ability of PM10 particles to irritate exposed mucous such as the eyes and throat. Differently, PM 2.5 travel all the way through the lungs into the alveoli, while nanoparticles or UFPs can penetrate through the respiratory system and into bloodstream, posing a higher hazard to human health. The World Health Organization (WHO) reported airborne particulate matter as a Group 1 carcinogen and as the biggest environmental risk to health, with responsibility for about one in every nine deaths annually. Fig. 1 shows the size range of common pollutant sources.

Then, the utilization of air quality monitoring devices that provide information on PM10 and PM 2.5 and UFPs levels enables a better particle pollution analysis and improves the development of new device-specific actions based on the detected aerosol type [15-17].

Air Quality Monitoring Devices For Particle Size

Historically, PM values are measured using

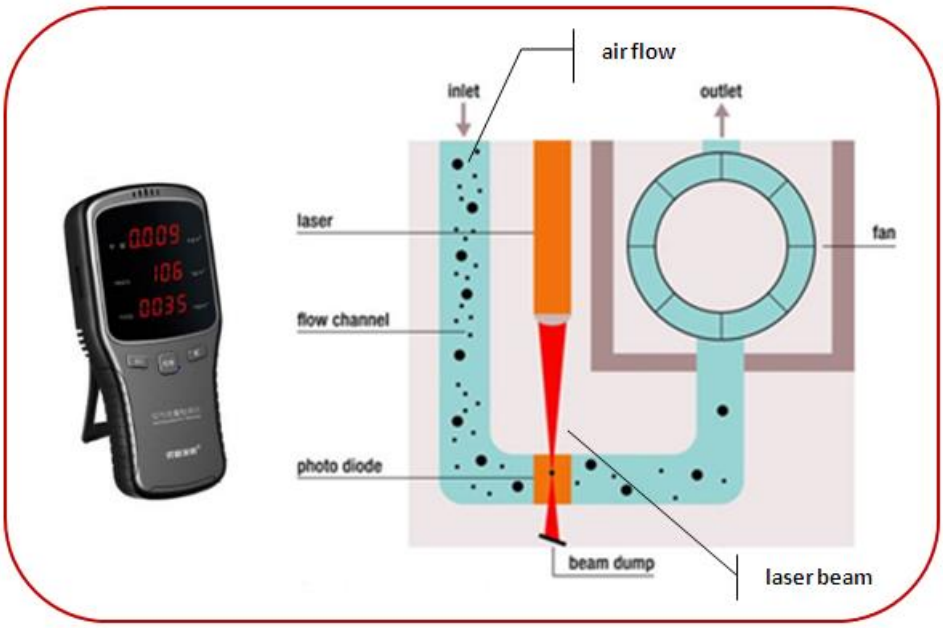

Fig. 2. Working principles of WP6910T indoor air quality monitor.

the gravimetric method and the results are expressed as 'mass concentration' in µg/m^3. This procedure uses a pre-weighed filter to collect ambient particles that are physically pre-sorted based on their size. At the end of the sampling period, the filter is weighed to determine the total accumulated PM mass in µg. Mass concentration is then obtained by dividing the mass increase of the filter by the 24-hour total volume of air that passed through the filter, resulting in a value in µg/m^3. Although gravimetric methods are long established as the most accurate way of determining mass concentration, they have some practical limitations to their diffusion in everyday applications: These instruments are bulky, very expensive, they process only one PM size per measurement, real-time sampling is not possible, and they cannot output the particle number count. For these reasons, real-time air quality monitors using mobile microscopy [11] and optical particle counters (OPCs) [12] have progressively substituted gravimeters. These instruments are based on different optical principles, typically scattering or absorption, with light scattering being the most commonly used. In these OPCs, the particle passes through the light source (usually a laser beam) and causes scattering of the incoming light, which is then detected by a photodiode and converted into real-time particle count and mass concentration values. This optical principle works well in terms of particle counting but are susceptible to estimation errors due to the different optical properties of the particles (e.g. shape and color) and different mass densities [13]. Moreover, the internal airflow engineering has a high impact on the accuracy of these sensors as particles can easily accumulate on their optical elements (laser, photodiode, beam-dump) and degrade their output over time if they are not properly engineered [14].

EXPERIMENTALS

Measurements were made using a WP6910T indoor PM2.5 and TVOC/ HCHO Air quality monitor detector meter analyzer by VSON (Vson Technology Co., Ltd., Bao'an area of Shenzhen City, China). The working principle of this instrument is based on laser scattering. In particular, a controlled airflow is created inside the sensor by means of a fan. As shown in Fig. 2, an internal feedback loop between the microprocessor and fan stabilizes the fan speed and therefore the airflow through the sensor. Environmental PM travels inside the sensor from inlet to outlet, carried by the airflow. In correspondence with the photodiode, particles in the airstream pass through a focused laser beam, causing light scattering. The scattered light is then detected by the photodiode and converted

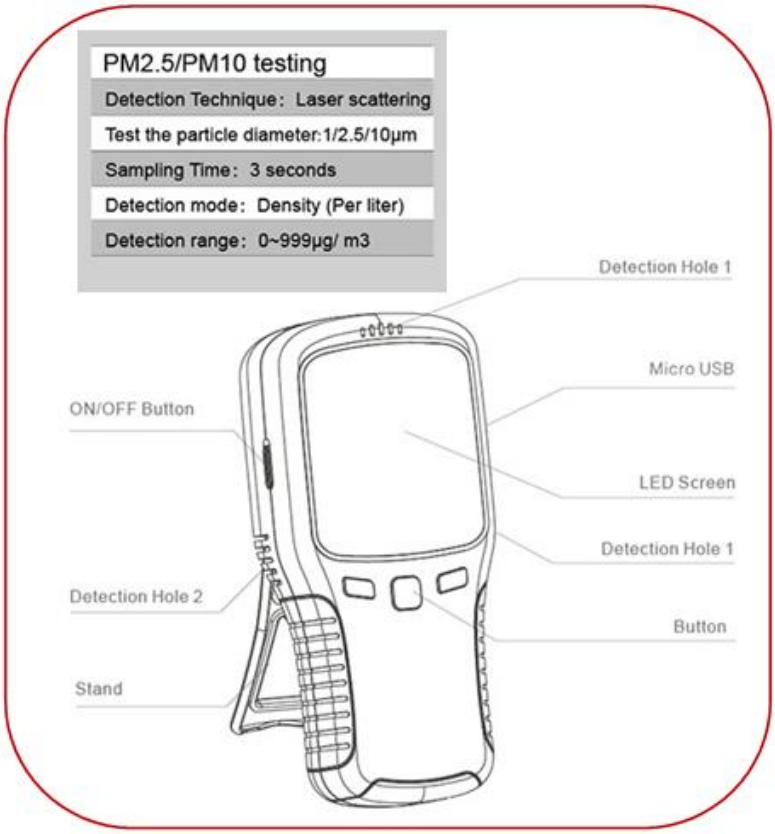

Fig. 3. Technical parameters of WP6910T indoor air quality monitor.

to a mass/number concentration output through an algorithm.

The algorithms make a fundamental difference in the estimation of mass concentration from the detected scattered light. In fact, some equations assume a constant mass density in calibration and calculate the mass concentration by multiplying the detected particle count by this mass density. This assumption only works if the sensor measures a single particle type also if, in everyday life, there are many different particle types with many different optical properties and are proposed algorithms that include different densities allowing a proper estimation of the mass concentration, regardless of the particle type measured. In this paper, the algorithm used to transform particle numbers to mass assumes that particles are spherical [15] and have a density of 1.65 g/cm^3, as suggested by Tuch *et al.* [16] and Weijers *et al.* [17].

RESULTS AND DISCUSSIONS

The manufacturer stated that WP6910T indoor air quality monitor is calibrated to detect 1/2.5/10 μm particle diameter (Fig. 3).

However, it is known the number of particles is inversely related to the diameter. For example, a study of Tittarelli *et al.*, [18] shows that, in the same measurement, were counted around 199000/ cm^3 PM in the range particles 0.3–0.5 μm, 37403/cm^3 in the range 0.5-0.7, 7139/cm^3 in the range 0.7-1 μm, 3054/cm^3 in the range 1-2.5 μm and only 200 /cm^3 particles of the size 2.5–10 μm. After transformation into mass, however, it was found that the fourth plus the fifth ranges provided the greatest contribution (almost 60%) to total PM10 and considering the first three ranges, the first (0.3–0.5 μm) provided the greatest contribution to PM10 (mean 21.2% of total), because of the high number of particles counted in that range (Table 1). The Analysis of the correlations (Pearson's R) between each of the ranges (Table 2) showed that the intermediate ranges (second, third and fourth (counting particles from 0.5 to 2.5 μm), correlated most strongly with each other. In fact, values for the first range (0.3–0.5 μm) correlated well (R= 0.74) with those of the second range (0.5–0.7 μm), but less well with all the others. Similarly, second

Table 1. Size, number and percentage of mass of PM.

Range	Size (μm)	Particle number	% of mass
1	0.3-0.5	199000/ cm^3	21.24
2	0.5-0.7	37403/cm^3	13.47
3	0.7-1	7139/cm^3	7.31
4	1-2.5	3054/cm^3	27.29
5	2.5-10	200 /cm^3	30.68
Total PM2.5			69.32
Total PM10			100

Table 2. Correlation between ranges (Pearson's R).

Range (μm)	1	2	3	4	5
1 (0.3-0.5)	1	0.74	0.57	0.48	0.40
2 (0.5-0.7)		1	0.95	0.88	0.69
3 (0.7-1)			1	0.97	0.80
4 (1-2.5)				1	0.90
5 (2.5-10)					1

range correlated well with range 3 and 4. Range 5 (>2.5–10 μm) correlated strongly with range 4 (R = 0.90) and range 3 (R = 0.80).

On the basis of these data a monitoring device able only to detect particle of μm size as the WP6910T indoor air quality monitor can be used to estimate the number and, consequently, the concentration in μg/m^3 of air nanoparticles. The correlation equation is [(concentration in μg/m^3 of PM 2.5* mass % of Range 1)/ mass % of total PM 2.5] For a example, a measured value of 35.91 μg/m^3 of PM 2.5 correspond to a value of 11 μg/m^3 [(35.91*21.24)/69.32-see Table 1] of particles in the range 300-500 nm with a Pearson's correlation of 0.48.

CONCLUSION

Nanosized ultra fine particles (UFPs) are the fraction of particulate matter with potential toxic effects. Despite of this, with low cost air quality monitors is impossible to detect particles under 1000 nm diameter, implying underestimation of the risk. The correlation found in this article permits to use low cost air quality monitors to have indicative data on measures that usually requires more expensive instruments. However, it is important to highlight that these findings do not suggest that particle counters should substitute conventional instruments but propose a valid alternative in producing epidemiological data for the evaluation of health effects of nanoparticle matter.

CONFLICTS OF INTEREST

The authors do not have any personal or financial conflicts of interest.

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