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A versatile generator of nanoparticle aerosols. A novel tool in environmental and occupational exposure assessment

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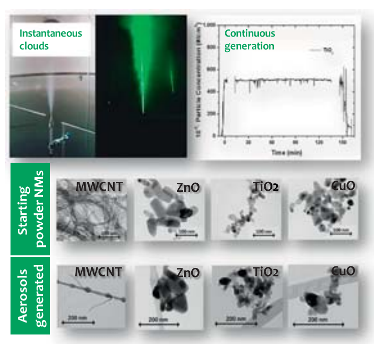
HIGHLIGHTS

- Novel high performance generator of nanoparticulate aerosols from dry nanosized powder.
- Portable aerosol generator and easy to operate.
- Exceptional flexibility in terms of: nature of materials to be aerosolized and concentration of the resulting atmosphere.
- Generator is able to produce: an instantaneous cloud or a continuous air stream containing a nanoaerosol.

GRAPHICAL ABSTRACT



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ABSTRACT

The increasing presence of nanotechnology on the market entails a growing probability of finding ENMs in the environment. Nanoparticles aerosols are a yet unknown risk for human and environmental exposure that may normally occur at any point during the nanomaterial lifecycle. There is a research gap in standardized methods to assess the exposure to airborne nanoparticles in different environments. The controllable generation of nanoparticle aerosols has long been a challenging objective for researchers and industries dealing with airborne nanoparticles. In this work, a versatile system to generate nanoparticulate aerosols has been designed. The system allows the production of both i) instantaneous nanoparticle clouds and ii) continuous nanoparticle streams with quasi-stable values of particle concentration and size distribution. This novel device uses a compressed-air pressure pulse to disperse the target material into either the testing environment (instantaneous cloud formation) or a secondary chamber, from which a continuous aerosol stream can be drawn, with a tunable nanoparticle concentration. The system is robust, highly versatile and easy to operate, enabling reproducible generation of aerosols from a variety of sources. The system has been verified with four dry nanomaterials: TiO_2, ZnO, CuO and CNT bundles.

1. Introduction

The last decade has witnessed unprecedented development of nanotechnology as a key enabling technology, pervading all areas of activity from basic science to industrial development (Lee et al., 2010; van Broekhuizen et al., 2012). The number and variety of nano-enabled

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consumer products is rapidly rising with extraordinary growth predictions for the next years (Lux Research, 2014).

From the environmental and health perspectives, the incidence of nanoscale matter is a matter of concern (Wagner et al., 2014). It has been shown that the presence of nanoparticle aerosols could have a significant impact in the global environment (Fadeel et al., 2013; Nel et al., 2006; Bakand et al., 2012; Behra and Krug, 2008), from the upper atmosphere to ground ecotoxicology. Airborne nanoscale matter has been related to several health issues (Nel et al., 2006) through inhalation of nanoparticles (Bakand et al., 2012). Especially relevant are those engineered nanoparticles that show enhanced surface chemical features which in turn may have a toxicological impact (Behra and Krug, 2008). Since the actual toxic impact of nanoparticles will continue to be a matter of debate until sound epidemiological data can be obtained (Krug, 2014); the precautionary principle should be applied when dealing with nanomaterials, especially in occupational scenarios (Ding et al., 2017).

Nanoparticle aerosols, whether intended or not, are ubiquitous in the production and handling of nanomaterials. Thus, many nanomaterial handling activities in both industrial locations and research laboratories have been shown to produce unintended aerosols containing respirable nanoparticles (Balas et al., 2010; Gomez et al., 2014; Fonseca et al., 2015a; Asbach et al., 2017; Fonseca et al., 2015b). On the other hand, nanoparticle aerosols are present by design in numerous manufacturing processes for nanomaterials (e.g. flame aerosol processes, laser pyrolysis, plasma-based methods or droplet-to-particle routes) (Sebastian et al., 2014). The widespread presence of nanomaterials demands a better understanding of their dynamics of aggregation and of the interaction of nanoparticle aerosols with environmental particles. Because of this, it would be highly desirable to produce aerosols with controlled characteristics from a variety of nanomaterials. The potential application scenarios are numerous. Thus, aerosol streams with concentrations representative of a potential exposure are needed to challenge protective materials (masks, gloves) and evaluate their performance (Golanski et al., 2010; Salah et al., 2015); aerosol clouds in a controlled environment (Clemente et al., 2014) would be very useful in aerosol research to validate models of aerosol dynamics and study aggregation and interaction with environmental particles (Mugica et al., 2017; Todea et al., 2017); creating tunable aerosol atmospheres would be valuable in the evaluation of the toxicity of inhaled nanoparticles in animal laboratory studies, providing a realistic alternative to the forced-inhalation and instillation systems commonly used today, etc.

There is no shortage of efforts to produce controlled nanoparticle aerosols. The most widely used method involves aerosolization of nanomaterial suspensions because it can provide aerosols from a wide variety of materials, provided that they can form stable suspensions in water or in other solvents (Fissan et al., 2014). These suspensions are dispersed in droplets, usually entrained in air to produce a nanoparticle aerosol as the solvent is evaporated. The main drawbacks are related to the presence of solvent molecules in the final nanoparticle stream and to nanoparticle agglomeration during the solvent drying stage (Kubo et al., 2014), with the final particle size governed by the size of the liquid droplets in the aerosol and the concentration of the nanoparticles in the starting suspension (Gomez et al., 2013). Because of its intrinsic characteristics, wet methods tend to produce aerosols that: i) have a high concentration of solvent, ii) present a wide particle size distribution, iii) face strong limitations in terms of nanoparticle concentration, and iv) are

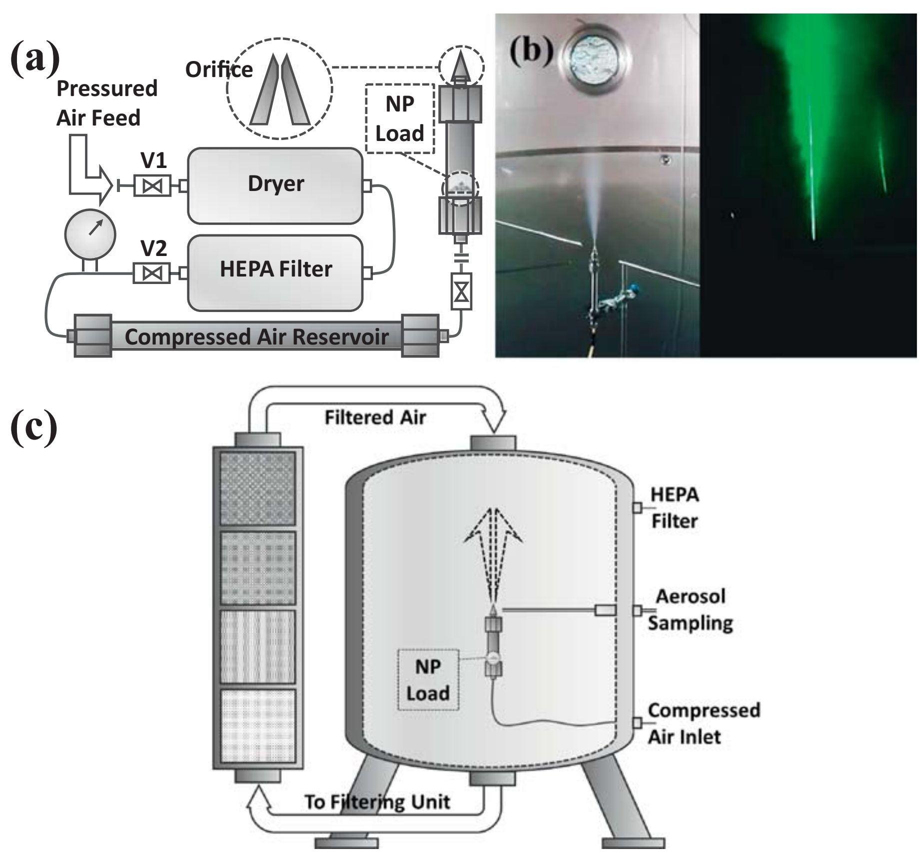

Fig. 1. Description of the system for the production of nanoparticulate aerosol clouds (a) schematic of the nanoparticle aerosol generator. Dried and filtered air is compressed into a 40-cm^3 stainless steel reservoir at pressures up to 8 bar. (b) A fast action valve releases this compressed air into a second (13 cm^3) chamber that contains the dried nanosized material, dispersing it into a cloud that is expelled through a 1.2-mm orifice. (c) Scheme of aerosol cloud release into a 13 m^3 test chamber. This is a specially designed facility whose atmosphere can be purified to a nearly particle-free level. Real time monitoring of particle concentration was carried out by continuous sampling near the emission point and the sampled air was replaced by an equivalent volume of HEPA-filtered air.