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A new dust generator for laboratory dust emission studies

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ABSTRACT

The aim of this study was to develop a cheap and replicable dust generator for production and investigation of fugitive dusts. We call the device the Easy Dust Generator (EDG). The EDG was constructed with common materials widely available in any laboratory so that it can be replicating anywhere in the world. In order to evaluate the performance of EDG, six repetitions of dust emissions on clay loam, sandy loam, loamy sand, and silt loam soils were measured. According to Gill et al. (2006), the EDG is a “Class C” dust generator. The emission curves obtained with EDG were similar to those obtained with other “Class C” dust generators such as the Lubbock dust generation sampling and analysis systems (LDGASS) and the Southard Laboratory dust generator, but with some differences in the absolute values. Maximum PM_{10} concentration was higher in fine texture than in coarse-textured soils. The average PM_{10} concentration and PM_{10} emissions per grams of soil ordered in the sequence loamy-sand < sandy loam < silt loam < clay loam. These results are in agreement with previous studies where PM_{10} emissions were higher in fine soils than in coarse soils. The standard deviation (SD) of the averaged PM_{10} concentration of all analyzed soils varied between 10% and 13%, being these values similar to those reported using other dust generator (from 6% to 24%). We concluded that the EDG can be reproduced anywhere in the world by using common materials and reliable PM_{10} emission measurements with good repeatability.

1. Introduction

A challenge of agriculture is to increase food production with the least environmental impact while preserving the natural resources. Agricultural activities release particles to the atmosphere with aerodynamic diameters smaller than 10 μm (PM_{10}) which have negative effects on the environment and human health (Prospero et al., 1983; Larney et al., 1998; Grantz et al., 1998; Norton and Gunter, 1999). The main sources of these particles are wind erosion, tillage operations and traffic on unpaved roads (Saxton, 1995; Chow et al., 1992; Holmen et al., 2001; Goossens and Buck, 2009). In all these cases, besides the natural soil emission capacity, other processes like the friction between particles or the breakdown of soil aggregates, can contribute to create larger amounts of PM_{10} than preexistent.

Field dust emission studies are time consuming and expensive. Furthermore, in field studies, the soil and climatic variability cannot be controlled. Field wind tunnel studies are an alternative to control time and wind velocity of an erosive event, but some other variables like soil moisture, soil homogeneity and temperature are difficult to control. Because of that lab studies with dust generators, which allow this kind of studies under controlled conditions, are an important method for determining the emission potential of different dust sources, their physical characteristics, chemical composition and environmental health and toxicological effects of the particulate matter emitted from different sources.

According to Gill et al. (2006), dust generators are classified as follows: based on fluidization (gas dispersion or ventilation), gravitation (drop or “impact” method) and mechanical dispersion or agitation (rotating drum and similar techniques). The fluidization generator simulates the direct suspension or re-suspension of pre-existing, loosed-fine particles from a solid surface under static conditions by drag or lift forces, but it does not transfer mechanical or kinetic energy to dust source materials (Gill et al., 2006). The gravitation and mechanical dispersion or agitation generator has been widely used to estimate the PM_{10} emission by wind erosion, tillage operations and traffic on unpaved roads. This kind of device transfers mechanical or kinetic energy to dust source materials, creating aerosols from the abrasion or fracture caused when grains of the source material collide with each other and/or the dust generator.

There are many commercial dust generators available, but the cost of those devices is several thousand of US dollars. There are also many non-commercial dust generators. Many of these require substantial engineering fabrication, some of them have not been

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calibrated and others lack sufficient construction details. According to Gill et al. (2006), relatively few systems have been strictly utilized for production and investigation of fugitive dusts or mineral aerosol for atmospheric particulate matter research. Two examples of non-commercial dust generators, developed for production and investigation of fugitive dusts or mineral aerosol, are the dust generation, sampling and analysis systems (LDGASS, Gill et al., 1999, 2006) and the Southard Laboratory dust generator (Domingo et al., 2010).

The LDGASS has been designed to simulate wind erosion of soils and sediments under field conditions, collecting a small portion of a large cloud of polydisperse dust aerosol from a relatively large source sample (Gill et al., 1999). The LDGASS consists of three separate modules. In the first one, dust is generated by applying energy to a bulk source sample by gravitation or mechanical dispersion. The "dust generation" module of the system comprises a small "dustfall tube" (gravitation dust generator). Entrained dust flows into an analysis module of the system, passing through the beam of a laser diffraction particle sizer (Malvern Instruments) located approximately 0.5 m downstream from the exit of the dust generator. Suspended aerosol flows an additional 0.3 m into a settling module for sampling $PM_{2.5}$ on an impactor and measuring dust concentration via a forward-scattering nephelometer (Gill et al., 2006).

The Southard Laboratory dust generator developed by Domingo et al. (2010) consists of two major components: the rotating chamber and the settling chamber. The rotating chamber has three steel baffles welded perpendicular to the interior drum surface. The rotating chamber rests on rubber wheels connected to a motor to rotate the steel drum. A blower is connected to a tube, which is threaded through the center of the rotating drum and penetrates the interior of the settling chamber. Inside the settling chamber, a small fan with blades helps to distribute the dust and in the upper portion of the settling chamber there are holes through which air pumps are connected to dust samplers (Domingo et al., 2010).

The not commercial dust generators described above require substantial engineering fabrication and their cost can be height. In view of this restriction the aim of this study was develop a cheap and replicable dust generator for the quantification of fugitive dusts or mineral aerosols.

2. Materials and methods

2.1. Easy Dust Generator (EDG) description

The EDG is composed by two parts: (1) a dust generating chamber and (2) a concentration chamber (Figs. 1 and 2).

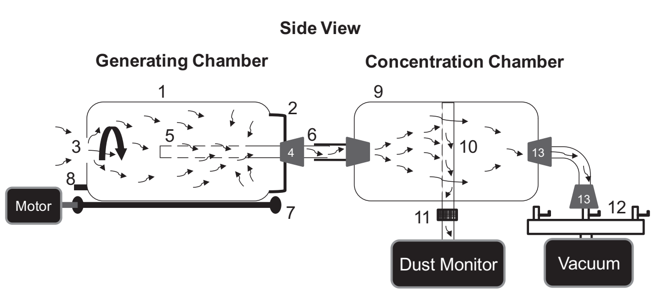

Fig. 1. Schematic of the Easy Dust Generator (EDG). where, 1 plastic bottle of the generating chamber, 2 screw cap, 3 orifice, 4 rubber stopper, 5 plastic tube with holes, 6 connection between the generation chamber and the concentration chamber, 7 mobile cylinder, 8 passive cylinder, 9 plastic bottle of the concentration chamber, 10 plastic tube, with holes, connecting the concentration chamber to dust monitor, 11 filter, 12 pipes with taps, 13 rubber stoppers. The bigger arrow shows the Generating Chamber rotation and the smaller arrows show the air circulation.

Fig. 1 shows a schematic of the Easy Dust Generator (EDG). The generating chamber, where the soil sample is placed, consists of a 116 mm wide and 200 mm tall plastic bottle (used for food storage) (1). Within this bottle, four 50 × 200 mm plastic blades (made with hard plastic) are installed with an angle of 30° to the bottle surface (Fig. 3). To install the blades the screw cap was removed (2). The blades mix the soil sample during bottle rotation. A 21 mm diameter orifice on one bottle extreme allows the free entrance of the air and is used to introduce the soil sample (3). On the other side of the bottle an 8 mm diameter plastic tube is inserted through a rubber stopper which is placed in a 21 mm diameter orifice avoiding air losses (4). The portion of the plastic tube inside the generating chamber has 4 rows of 5 holes (2 mm diameter) placed 15 mm apart along the tube (5). The rows are placed perpendicularly each other over the plastic tube. The portion of the plastic tube outside the generating chamber is coupled to a glass tube connected to the concentration chamber (6). This mechanism allows the rotation of the generating chamber while the concentration chamber is stationary.

The generating chamber rests on two cylinders: a 270 mm long and 32 mm wide mobile one (in this case a commercial printer cylinder) and a 270 mm long and 10 mm wide passive cylinder (in this case a glass tube which rotates freely over a 270 mm long and 8 mm wide solid pipe) (7 and 8). A small electric motor (Zhaoqing Wei Li Co., LTD, AC: 220 V/240 V–50/60 Hz–4 W) rotates the mobile cylinder at 30 rpm, which moves the generating chamber at 6 rpm. The cost of this motor ranges from 10 to 15 US dollars, depending on their rotation velocity.

The concentration chamber is a 116 mm wide and 250 mm long plastic bottle (9). Within this chamber a 9 mm diameter and 150 mm long plastic tube is placed in the middle of the concentration chamber, perpendicularly to its main axis (10). This plastic tube has a row of 8 orifices of 2 mm diameter and 15 mm apart. This plastic tube connects the concentration chamber with a PM_{10} dust monitor, in this case a Kanomak model 3442. The hose connecting the concentration chamber with the PM_{10} dust monitor has a filter 0.074 mm mesh to retain larger particles that can damage the dust monitor (11).

A vacuum source is connected to the distal extreme of the concentration chamber through a 10 mm diameter pipe. Three pipes with taps connect the concentration chamber with the vacuum source (12). The taps allow the regulation of the air flux aspirated by the vacuum bomb, which maximum aspiration capacity is 4.3×10^{-3} m^3 min^{-1}. The plastic tube that connects the concentration chamber and the vacuum bomb has two rubber caps that seal the connection (13).

2.2. EDG operating mode

The soil sample (1.5 g), previously sieved by 0.5 mm without crushing the material, is dropped inside the generating chamber. This amount of soil was choosing because it generated a PM_{10} concentration that did not exceed the dust monitor detection range of 10 mg m^{-3}. The soils were passed through a 0.5 mm diameter sieve in order to avoid the interference of large aggregates of more developed and structured soils and to make PM_{10} emission comparable among soils. According to Gill et al. (2006) some dust-generating systems use more or less undisturbed soil samples, while others sieve or pre-separate the source materials like the LDGASS (Amante-Orozco, 2000) and the UC Davis re-suspension test chamber (Carvacho et al., 2004). Once sieved, the soil sample is dropped into the generating chamber, and the dust monitor, the vacuum source and the electric motor are sequentially switched on. The generating chamber rotates and transports the soil sample from the bottom to the top, from where it falls (Fig. 3). During the fall, the dust particles collide and impact with the chamber wall,