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Novel approach to model microstructure of dust-deposits comprised of polydisperse particles of arbitrary shapes

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ABSTRACT

Morphology of airborne particles plays a key role in the growth rate of dust-cake formed on an exposed solid surface, or on the face of an air filter. The work presented in this paper reports on a fast and flexible algorithm to simulate the microstructure of dust-cakes resulting from deposition of non-inertial airborne particles of arbitrary shapes. Our approach is based on representing a non-spherical particle as an assembly of spherical beads connected to one another via springs and dampers. This mass-spring-damper (MSD) model allows one to study the effects of particle shape, particle size, and particle rigidity on the thickness and porosity of the dust-cakes that result from deposition of such aerosol particles in different applications. In aerosol filtration applications for instance, the ability to predict the thickness and porosity of a dust-cake comprised of non-spherical particles is needed before one can predict the pressure drop or collection efficiency of a dust-loaded filter. For demonstration purposes in this paper, dust-cakes comprised of particles with cubical and spherocylindrical shapes as well as Jacks-toy and Plus-sign shapes are simulated and discussed.

1. Introduction

Deposition of airborne particles on an exposed surface can lead to the formation of a dendritic dust-deposit (often referred to as dust-cake) over the surface. The ability to measure the thickness and porosity of such dust-cakes is important in a variety of applications, as uncontrolled accumulation dust particles can harm electronic equipment by blocking the heat transfer from the heated components, affect the sensitivity of measurement tools, or contaminate consumable products, among many others. Moreover, undetected accumulation of combustible dust may result in fire and/or explosion, leading to property damage and potential life-threatening situations [1,2]. In the context of aerosol filtration, growth of dust-cakes on the surface of a filter creates significant pressure drop for the system in which the filter is utilized. This is especially the case with high-efficiency filters that operate in the so-called surface filtration regime, where the majority of the collected particles deposit on the surface of the filter (as opposed to depositing inside the filter media) [3–8]. Accurate measurement of the porosity and thickness of a dust-cake is not trivial as the particles are often non-spherical in shape and they vary in size, and their dendritic structures are often soft and deformable [9,10]. Moreover, most conventional thickness measurement techniques are only suitable for local measurements at nano- or micro-scales (e.g., AFM microscopes, profilometers, indenters…), and can become ineffective when used to estimate the porosity of a non-homogenous dust-cake comprised of deformable (and moveable) dendritic structures [11–16]. Computer simulation is a convenient means for predicting how the thickness of a dust-cake grows over time, or how its porosity depends on the size or shape of the depositing particles. Unfortunately, however, the majority of the computational models developed to study microstructure of a dendritic particle cake (resulted from airborne dust deposition on a filter or a surface) have considered a spherical shape for the dust particles [17–25]. While this assumption significantly simplifies the mathematical aspects of the problem, it does not allow one to study the impact of particle shape on the rate of growth of cake thickness or its porosity. This is particularly important as most dust particles are non-spherical, and in some cases may have elongated geometries, e.g., asbestos particles [26]. It is also quite possible that a dust-cake is comprised of various non-spherical aerosolized particles with different dimensions, which further complicates the problem at hand. The main challenge in simulating the microstructure of a dendrite comprised of particles of arbitrary shapes is to predict the location of the point of contact between the particles (which is only easy if the particles are spherical) to prevent penetration of the modeled particles into one another (non-physical). The current work presents a fast algorithm for modeling deposition of dust particles of arbitrary shapes on top of one

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