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Filtration efficiency of an electrostatic fibrous filter: Studying filtration dependency on ultrafine particle exposure and composition

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ABSTRACT

The objective of the present study is to investigate the relationship between ultrafine particle concentrations and removal efficiencies for an electrostatic fibrous filter in a laboratory environment. Electrostatic fibrous filters capture particles efficiently, with a low pressure drop. Therefore they have applications in building ventilation systems. The relationship between particle removal efficiency and particle concentration has not been widely investigated in ventilation systems and indoor environments. In order to achieve the objective of this study, experiments were performed in a controlled laboratory environment using two different particle counters: a Scanning Mobility Particle Sizer and a NanoTracer. Particles were generated at different concentrations by burning a pure wax candle in a test room. The set-up consisted of a test room, a fan a duct and the particle filter. The results show that the efficiency of the electrostatic fibrous filter increased with increasing exposure levels. The filter efficiency varies from 45% to 80% depending on the particle concentrations and particle sizes including ultrafine particles. The results are consistent with a mechanism in which the particles deposit on the fibers and form chain-like agglomerates known as dendrites. The dendrites themselves contribute in capturing the other particles. Increasing exposure will result in increasing the number of the dendrites because of the static charging and consequently increasing the efficiency. Static electrical charging of dendrites will spread out the branches, increasing capture.

1. Introduction

A great deal of research has been devoted to determining the health effects of aerosol particles on human. It has been established that an increase in the particle concentration is associated with airway inflammations and reduced lung function (Pope, 2002; Strak et al., 2012). In the present study, the removal efficiency of an electrostatic fibrous filter for particles was examined using a burning candle as a particle source. Candles generate large numbers of particles with

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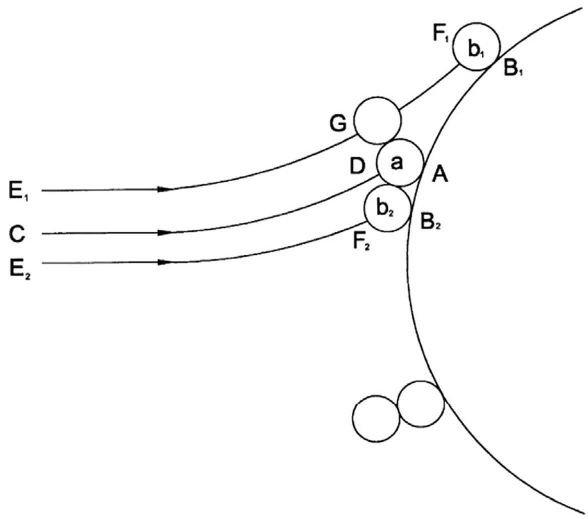

Fig. 1. Shadowing effect and chain-like deposition.
Figure based on Wang (2001).

different particle sizes including ultrafine, fine and coarse particles (Afshari et al., 2005). The level of particles generated by candles has been shown to exceed the European Union air quality guideline. In addition, the DNA damage of different sizes of particles has been investigated. According to this study, ultrafine particles have higher DNA damage than fine particles and coarse particles (Chuang et al., 2012).

A fibrous filter is a filter comprising large number of small fibers ranging from nano-size fibers to microfibers. The filters and their characteristics have been studied with regards to their pressure drop, penetration ratio and filter efficiency (Japuntich et al., 1994; Kim et al., 2006; Li & Jo, 2010).

Particles are trapped in filters due to diffusion, interception, impaction, electrostatic charge and gravitational settling. The effect of each of these mechanisms depends differently on the size of the particles. A minimum in efficiency has been reported for particle diameters of 100 nm to 300 nm for which the effects of diffusion and impaction are the lowest. Billings (1966) investigated the dendrites and their properties including shape and dependency to the time interval in which the filter is under operation. Moreover, the filter efficiency for different sizes of particles has been evaluated regarding the effect of air velocity. As velocity increases the efficiency for removing ultrafine particles also decreases (Stafford & Ettinger, 1972).

After impingement of the first particle to the filter fiber, there is an increased probability that other particles will impact on this particle and build chain-like shapes called dendrites. Tien et al. introduced a theory to explain the formation of a dendrite on a fiber in a flow (Tien et al., 1977). As shown in Fig. 1, after impingement of the first particle (a), following particles (b_1 and b_2) will attach to the first particle, if their trajectory targets a point in the arc of B_1B_2 shown in the figure. This phenomenon is called the shadowing effect.

Considering the interception and impaction effects, it has been possible for researchers to propose some theoretical models of dendrite shape and their rate of its formation (Payatakes & Tien, 1976; Payatakes, 1977).

Walsh & Stenhouse (1997) have shown that the size, charge and composition of aerosol particles have a significant effect on the performance of fibrous filters. The authors concluded that smaller particles cause filters to be blocked more quickly and the blockage consequently reduces the efficiency of the filter. The reason is because smaller particles have larger specific surface area and the structures formed by smaller particles have a more clogging effect (Walsh et al., 1996).

In addition, the effect of relative humidity on the ultrafine particle filtration efficiency has been investigated. It was seen that there is no effect of humidity on the filtration efficiency for ultrafine particles (Kim et al., 2006). This study also found that particle charge is correlated with trapping efficiency, more charge leading to lower permeability.

The effect of the filter's charge on trapping efficiency has been tested in two studies (Baumgartner et al., 1986; Baumgartner & Löffler, 1986). According to the work of Baumgartner and Löffler, the efficiency of the charged filters for particles from 10 nm to 10 μm diameters is higher than for a normal glass fiber filter.

The aim of this study is to investigate the effect of the total exposure of particles on the fractional efficiency of a fibrous filter.

2. Methodology

The initial stage of the study was performed using an electrostatic filter with a density of 80 g/m^2 mounted in a duct system to evaluate the efficiency of the filter as a function of exposure to ultrafine particles (UFPs). The thickness of the filter was 3.4 mm. The experiment consisted of a test room, a fan a duct and the particle filter. The duct system was connected to a test room. The experiments were carried out in the laboratory of the Danish Building Research Institute (SBi), Aalborg