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Effect of wall surface materials on deposition of particles with the aid of negative air ions

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Abstract

This work studied how wall surface materials influence the removal of airborne particles with negative air ions (NAIs) in indoor environments. Five wall surface materials—stainless steel, wood, PVC (polyvinyl chloride), wallpaper and cement paint—were applied to the inner surface of a test chamber. Two monodispersed solid NaCl particle sizes, 300 and 30 nm, were tested. The NAIs in the chamber were generated by negatively electric discharge in the range 3000–5000 ions cm^{-3}. Experiments on the natural decay and application of NAIs were conducted at an air exchange rate of 1 h^{-1}. The decay coefficient, the removal efficiency, the time to halve the concentration (T_{50}) and the effective cleaning rate (ECR) were taken into account. The experimental data revealed that NAIs enhanced the removal of both 300 and 30 nm particles for each wall surface material. The decay coefficients of the NAI applications (k_a) were 2.9–7.4 and 2.5–4.0 times higher than those of natural decay (k_n) for 300 and 30 nm particles, respectively. However, the effect of the wall surfaces on the removal of particles was observed in both natural decay and NAI application experiments. The order of natural decay for 300 and 30 nm particles under different wall surfaces was cement paint > PVC ≅ wallpaper ≅ wood > stainless steel, as perhaps determined by the roughness of the wall materials. The overall removal efficiencies of 300 and 30 nm particles during 30 min of NAI emission were over 60% and 80%, respectively, in the chamber with wood and PVC wall surfaces. The half concentration times (T_{50}) of NAI applications for various wall surfaces were less than 20 min, except for stainless steel and cement paint walls. The ECR demonstrated that the net effects of the NAIs for 300 nm particles followed the order wood (34.6 Lpm) > PVC (33.3 Lpm) > wallpaper (27.0 Lpm) > stainless steel (16.6 Lpm) > cement paint (14.8 Lpm). The ECR for 30 nm particles followed the order wood (41.4 Lpm) > PVC (30.4 Lpm) ≅ cement paint (30.3 Lpm) > wallpaper (27.7 Lpm) > stainless steel (20.1 Lpm). The NAI could remove particles from the wood and PVC

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wall surfaces substantially more effectively than from other wall materials. The various electrical characteristics and roughness of the wall materials may have been responsible for the associated of the various ECRs with the various wall surface materials.

Keywords: Negative air ion; Particle deposition; Wall material; Decay coefficient; Electrical property

1. Introduction

Negative air ionizers are typically applied to clean air indoors. Daniels (2002) reported that negative air ions (NAIs) reduce aerosol particles, airborne microbes, odors and volatile organic compounds (VOCs) in indoor air. The removal of aerosol particles using NAIs is efficient (Grabarczyk, 2001; Wu & Lee, 2003). The mechanisms of particle removal by NAI include particle charging by emitted ions and electromigration (Lee, Yermakov, & Grinshpun, 2004a,b). The charged aerosol particles and the electric field produced by the electrical discharge increase the migration velocity towards the indoor surfaces (Lee et al., 2004a,b; Mayya, Sapra, Khan, & Sunny, 2004). Particles are finally deposited on indoor surfaces, such as wall surfaces. The deposition of particles on various wall materials has been studied. A glass chamber (Crump, Flagan, & Seinfeld, 1983), an acrylic chamber (Okuyama, Kousaka, Yamamoto, & Hosokawa, 1986), Teflon film bags (McMurry & Rader, 1985) and aluminized Mylar bags (Cooper, Langer, & Rosinski, 1979) have been used, but the effects of various wall materials has not been considered. Although many decorating materials are used in rooms, few studies have evaluated the effect of wall surface materials on the removal of particles by NAIs.

These NAIs are negatively charged small airborne ions with an average electric mobility of $1–2\,cm^2\,V^{-1}\,s^{-1}$ (Krueger & Reed, 1976). Luts and Salm (1994) indicated that superoxide ($O_2^{\cdot -}$) is the primary negatively charged NAI species and is more stable than other NAIs (Goldstein, Goldstein, & Merzlyak, 1992; Kosenko, Kaminsky, Stavrovskaya, Sirota, & Kondrashova, 1997). The typical lifetime of NAIs in clean air is approximately 100 s (Parts & Luts (2004); Daniels, 2002). Kondrashova et al. (2000) indicated the beneficial biological effects of NAIs. Furthermore, studies have investigated the application of NAIs in hypertension therapy and the role of NAIs in promoting recovery from stress- and exercise-based injuries (Kondrashova et al., 2000; Ryushi et al., 1998).

Particles in indoor air are deposited following transport to the boundary layer of the surfaces in a room. Crump and Seinfeld (1981) studied a wall deposition theory of particles in an enclosed vessel explained the motion of aerosol by turbulent transport, Brownian diffusion and gravitational sedimentation. Park, Kim, Han, Kwon, and Lee (2001) investigated the loss rate of polydispersed aerosols from a wall, correcting the model of Crump and Seinfeld (1981) for the polydispersity effects of polydispersed aerosols. Park et al. (2001) found that the wall loss rate of polydispersed aerosols exceeded that of monodispersed aerosols. McMurry and Rader (1985) proposed a wall deposition theory of particles in spherical, electrically charged chambers, for aerosol moved by electrostatic drift, or exhibiting turbulent movement, Brownian diffusion and gravitational sedimentation. The study conclusively established that electrostatic effects dominate for 0.005–1.0 μm particles. Nomura, Hopke, Fitzgerald, and Mesbah (1997) investigated the deposition of particles in a chamber as a function of size and ventilation rate, and indicated that the approach of Benes and Holub (1996) provided a more reasonable fit to the experimental data than the model of Crump and Seinfeld (1981). However, models for estimating the deposition of particles on a