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A simulation of unsteady-state filtration via nanofiber media at reduced operating pressures

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Abstract

In this work, 3-D structures resembling nanofiber ($d_f < 200$ nm) filter media are simulated and challenged with nanoparticle aerosols at reduced operating pressures. For the range of fiber diameters considered in this paper, the free molecular flow regime is dominant. Therefore, the disturbances to the air flow field caused by the fibers are neglected. Nanoparticle capture efficiency of nanofiber webs, due to Brownian diffusion and interception, is calculated for particle diameters ranging from 50 to 500 nm. Our simulations show that by decreasing the fiber diameter, the minimum collection efficiency of filtration media having identical pressure drops increases. This effect is accompanied by a decrease in the particle diameter associated with these minimum efficiencies—the most penetrating particle diameter. Moreover, it is demonstrated that increasing the flow temperature enhances the nanoparticle capture efficiency of nanofiber filters. Allowing the particles to deposit on the fibers as well as each other, the caking process of such nanofiber filters is simulated for different monodisperse and polydisperse aerosols at different temperatures. The statistical information regarding the composition of nanoparticle cakes formed at high and low temperatures is presented and discussed.

Keywords: Filtration; Nanofiber; Nanoparticle; Caking; Nonwoven filter; Electrospinning

1. Introduction

Our rapidly growing competitive industries, nowadays, require engineers to design aerosol filters tailored for different specific applications. Fibrous filters are generally characterized by their collection efficiency and pressure drop. It is important to explore possible ways of predicting a filter's performance when it is challenged with aerosol flows in order to minimize the time and cost of producing more effective products. During the past decades, there have been many pioneering works which have formed the basis for filtration science and technology (Abdel-Ghani & Davies, 1985; Brown, 1984; Dhaniyala & Liu, 1999; El-Shoboskshy, Al-Sanea, & Adnan, 1994; Happel, 1959; Jackson & James, 1986; Kirsh, 2003; Kuwabara, 1959; Lee & Liu, 1982; Li & Park, 1997; Lisowski, Jankowska, Thorpe, & Brown, 2001; Overcamp, 1985; Ramarao, Chi, & Mohan, 1994; Rao & Faghri, 1988; Rodman & Lessmann, 1988; Spurny, 1986; Stechkina & Fuchs, 1965; Termonia, 1998; Thomas, Penicot, Contal, Leclerc, & Vendel, 2001; Zhu, Lin, & Cheung, 2000). However, in most of these studies the filter geometry has been simplified to rows of regularly arranged fibers, often in 2-D geometries, perpendicular to the flow direction. This is probably because of the difficulties involved in

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