Chemical Engineering Science 65 (2010) 5285–5293

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Note

Influence of fiber orientation distribution on performance of aerosol filtration media

S. Fotovati [a], H. Vahedi Tafreshi [a,*], B. Pourdeyhimi [b]

[a] Mechanical Engineering Department, Virginia Commonwealth University, Richmond, VA 23284-3015, USA
[b] Nonwovens Cooperative Research Center, The Nonwovens Institute, NC State University, Raleigh, NC 27695-8301, USA

ARTICLE INFO

Article history:
Received 5 November 2009
Received in revised form
14 June 2010
Accepted 24 June 2010
Available online 4 July 2010

Keywords:
Aerosol
Filtration
Porous media
Fibrous materials
3-D Modeling
Fiber orientation

ABSTRACT

This work is conducted to better our understanding of the influence of fibers' in-plane and through-plane orientations on pressure drop and collection efficiency of fibrous media. The Stokes flow equations are numerically solved in virtual, 3-D, fibrous geometries with varying in-plane and/or through-plane orientations. Pressure drop and aerosol collection efficiency characteristics of such media are calculated and compared with available studies from the literature. Our results indicate that pressure drop and submicron particle capture efficiency of common fibrous filters with a fiber diameter of about 10 μm are independent of the in-plane orientation of the fibers, but decrease with increasing the fibers' through-plane orientation. More interestingly, it was found that filters with higher through-plane fiber orientations have a higher figure of merit if challenged with nanoparticles. The figure of merit of these media, however, decreases as the particle size increases, reversing the effect of fibers' through-plane orientation. It was also shown that when the diameter of the particles is comparable to that of the fibers, collection efficiency increases with decreasing the fibers' in-plane orientation, while the pressure drop remains almost unchanged. This indicates that decreasing the fibers' in-plane orientation increased the figure of merit of media made of nanofibers.

1. Introduction

Fibrous filters are generally characterized by their collection efficiency and pressure drop. During the past 50 years, there have been many studies dedicated to the development of mathematical theories for predicting collection efficiency and pressure drop of fibrous media (see Brown, 1993 and Spurny, 1998 for a complete review). Developing a general filtration theory is computationally expensive, and consequently, almost all previous models were based on oversimplified 2-D geometries in which the fibers were placed in square or hexagonal arrangements perpendicular to the flow. Results of such 2-D models were then modified with a variety of empirical correction factors to compensate for errors introduced to the models by unrealistic initial assumptions. The microstructure of disordered fibrous materials can, in general, be classified into three major categories: unidirectional structures, where axes of all cylindrical fibers are parallel with one another (e.g., Spielman and Goren, 1968) (see Fig. 1a); random layered (planar) structures, where axes of cylindrical fibers lie randomly in parallel planes often perpendicular to the flow direction (e.g., Koponen et al., 1998; Dhaniyala and Liu, 1999; Tomadakis and Robertson, 2005; Wang et al., 2007; Jaganathan et al., 2008; Tafreshi et al., 2009; Tahir and Tafreshi, 2009; Hosseini and Tafreshi, 2010a) (Fig. 1b); and three-dimensionally isotropic structures, where fibers axes can be randomly oriented in any direction in 3-D space (e.g., Spielman and Goren, 1968; Clague and Phillips, 1997; Tahir and Tafreshi, 2009); (Fig. 1c).

Even though numerous analytical and experimental investigations have been devised to study fibrous filters, influence of fiber orientation on filtration efficiency of a fibrous medium has not been sufficiently explored. For instance, effects of fibers' in-plane orientation in Fig. 1b or through-plane orientation in Fig. 1c have not been well documented. Banks and his co-workers were the first to develop a single-fiber model to study the effects of through-plane fiber orientation on pressure drop and particle collection filtration due to Brownian diffusion (see Banks, 1987 and Banks et al., 1990). Schweers and Löffler (1994) contributed to this field by publishing an expression for predicting the role of through-plane fiber orientation in particle capture due to interception. These authors developed a macroscale model for predicting the filtration efficiency of a non-homogenous filter medium. The macroscale model of Schweers and Löffler (1994) was constructed by dividing a non-homogenous filter medium into a series of inter-connected Kuwabara cell models (ordered 2-D models) with different microstructural parameters (fiber diameter, SVF…). Schweers and Löffler (1994) used the

* Corresponding author. Tel.: +1 804 828 9936; fax: +1 804 827 7030.
E-mail address: htafreshi@vcu.edu (H. Vahedi Tafreshi).

0009-2509/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2010.06.032