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A case study of simulating submicron aerosol filtration via lightweight spun-bonded filter media

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Abstract

The most common method of filtration is via fibrous nonwoven media. Fibrous filters are generally characterized by their collection efficiency and pressure drop. Traditional computational studies in this area are typically based on unrealistic 2-D geometries with the fibers simply placed in a lattice (regular array) perpendicular to the flow. The traditional approaches however, do not permit studying the relation between the 3-D structure of a filter media and its performance. In this study, for the first time, a virtual 3-D web is generated based on the fiber orientation information obtained from analyzing microscopic images of lightweight spun-bonded filter media. Pressure drop and collection efficiency of our virtual filter are simulated and compared with the previous 2-D analytical and numerical models as well as experiment. Our pressure drop calculation, unlike the previous models, showed a perfect agreement with the predictions of the Davies' empirical equation. The collection efficiencies obtained from simulating a thin spun-bonded filter media challenged with submicron particles having diameters ranging from 50 to 500 nm showed a similar trend as that of the previous 2-D models. For the solid volume fraction (SVF), filter thickness, and the fiber and particle diameters considered in this study, we found collection efficiencies higher than that of the above mentioned 2-D models with a relatively good agreement with experimental data obtained from a TSI 8130 filter tester.

Keywords: Aerosol; Filtration; Product design; Fluid mechanics; Modeling

1. Introduction

The rising awareness of environmental agencies and the general public for a clean environment together with demands of many advanced industries, such as electronics, medical, pharmaceutical, and biological research, have urged the filtration industry to investigate on ways to improve the indoor air quality for the past decades (Maynard and Kuempel, 2005). The most common method of removing particles from a gas stream is via fibrous filters which are generally characterized by two basic parameters: collection efficiency and pressure drop. During the past decades, there have been many pioneering studies, dealing with either a single fiber or a structured array of fibers, which have helped developing the filtration science and technology to its current level (Happel, 1959; Kuwabara, 1959; Stechkina and Fuchs, 1965; Lee and Liu, 1982; Brown, 1984; Abdel-Ghani and Davies, 1985; Overcamp, 1985; Jackson and James, 1986; Spurny, 1986; Rao and Faghri, 1988; Rodman and Lessmann, 1988; El-Shoboskshy et al., 1994; Ramarao et al., 1994; Li and Park, 1997; Termonia, 1998; Dhaniyala and Liu, 1999; Zhu et al., 2000; Thomas et al., 2001; Lisowski et al., 2001; Kirsh, 2003). However, most of the previous studies have been limited to systems consisting of rows of fibers (often in 2-D geometries) perpendicular to the flow direction. To our knowledge, there has been no attempt in realistically simulating the filter's disordered structure in a 3-D geometry. Moreover, the role of the filter structure and its relationship with performance of the media has not yet been established. This is probably because of the difficulties involved in generating 3-D structures similar to that of a filter media as well as calculating the particle capture efficiency when the geometry is too complex. The current

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