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Analytical expressions for predicting capture efficiency of bimodal fibrous filters

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A B S T R A C T

In this work, a series of numerical simulations are formulated for studying the performance (collection efficiency and pressure drop) of filter media with bimodal diameter distributions. While there are numerous analytical expressions available for predicting performance of filters made up of fibers with a unimodal fiber diameter distribution, there are practically no simple relations for bimodal filters. In this paper, we report on the influence of the fiber diameter dissimilarity and the number (mass) fraction of each component on the performance of a bimodal filter. Our simulation results are utilized to establish a unimodal equivalent diameter for the bimodal media, thereby taking advantage of the existing expressions of unimodal filters for capture efficiency prediction. Our results indicate that the cube root relation of Tafreshi, Rahman, Jaganathan, Wang, and Pourdeyhimi (2009) offers the closest predictions for the range of particle diameters, coarse fiber number (mass) fractions, fiber diameter ratios, and solid volume fractions (SVF) considered in this work. Our study revealed that the figure of merit (FOM) of bimodal filters increases with increasing fiber diameter ratios for Brownian particles ($d_p < 100$ nm), and decreases when challenged with larger particles. It has also been shown that when increasing the ratio of coarse fibers to fine fibers, FOM increases for Brownian particles, and decreases for larger particles.

1. Introduction

Aerosol collection efficiency of fibrous media has been studied for many years, and there are many analytical, numerical, and/or empirical correlations available for conveniently calculating the performance of a filter. In almost all of these studies, however, a fibrous medium is assumed to be made up of fibers with a unimodal fiber diameter distribution (referred to hereafter as unimodal media). Many fibrous filters, however, consist of blends of coarse and fine fibers (referred to hereafter as bimodal media). In these filters, fine fibers contribute to the high filtration efficiency while coarse fibers provide mechanical rigidity. Bimodal media are typically comprised of coarse fibers with a diameter of about 3 μm and fine fibers with a diameter of the order of 0.3 μm (e.g., glass fiber filters). Such fine fibers at normal temperatures and pressures allow the so-called "slip flow" to occur at the fiber surface. The slip effect is known for reducing the resistance of a fiber against an air stream, and can desirably reduce the filter's pressure drop.

Despite their importance, bimodal (or multimodal) media have not been adequately studied in the literature, and unlike the case of unimodal media, there are no simple expressions/correlations that can be used to predict their collection

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