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Analytical expressions for predicting performance of aerosol filtration media made up of trilobal fibers

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ABSTRACT

Despite the widespread use of fibrous filtration media made up of trilobal fibers (referred to as trilobal media here), no mathematical formulations have yet been developed to predict their collection efficiency or pressure drop. In this study, we model the cross-section of a trilobal fiber with three overlapping ellipses separated from one another by a 120° transformation. We generate 2-D models representing the internal structure of trilobal filters having fibers with different dimensions and aspect ratios, and used them to predict pressure drop and collection efficiency of trilobal filter media. This information is then utilized to define an equivalent medium with circular fibers for each trilobal filter. Our results indicate that the circumscribed circle of a trilobal fiber can serve as an equivalent circular diameter, and therefore be used in the existing empirical/semi-empirical correlations that have previously been developed for predicting performance of filters with circular fibers. We have also proposed easy-to-use expressions that can be used with our equivalent circumscribed diameters for calculating the pressure drop of trilobal media.

1. Introduction

Fibers with trilobal cross-sections are currently used for air and water filtration in variety of applications [1–3]. An example of such media is a family of Spun-bonded Polyester fibers produced by BBA Fiberweb and sold under the brand name REEMAY. Since the infancy of filtration theory, about fifty years ago, fibers have been assumed to have circular cross-sections. There are many analytical, numerical, and empirical correlations available for predicting the collection efficiency and pressure drop of fibrous media made of fibers with circular cross-sections (referred to as *circular media* here for brevity). Our extensive literature search resulted only in a very few studies reporting filtration performance of media with trilobal fibers (referred to as *trilobal media* here for brevity). This includes the experimental studies of Lamb and Costanza [2], and Sanchez et al. [3], as well as the numerical simulations of Raynor and Kim [4]. To the knowledge of the authors, however, no analytical expressions have yet been proposed for predicting the performance of filters with trilobal fibers. Our objective in this paper is to establish simple analytical expressions that allow investigators to predict collection efficiency and pressured drop for their trilobal fibrous filters. We will also discuss and compare the performance of filters made of trilobal fibers with their equivalent media made of circular fibers. In particular, we conduct a series of computational fluid dynamics (CFD) simulations to determine an equivalent circular fiber diameter, thereby taking advantage of the existing expressions developed in the past for filters with circular fibers.

In the next section, we present a brief summary of the popular expressions available for predicting performance of filters with circular fibers. This is followed by our geometrical representation of trilobal cross-sections in Section 3. Fluid flow governing equations, particle trajectory formulations, and further details about the simulations are presented in Section 4. In Section 5, we present our results and discussion. This is followed by Section 6 where we compare findings of our 2-D simulations, obtained by enhancing the Fluent CFD code, with the 3-D simulation results obtained using FilterDict software (www.geodict.com) for verifications. Summary of the work and our conclusions are presented in Section 7.

2. Aerosol filtration via filters with circular fibers

There are various expressions that have been developed for predicting pressure drop and collection efficiency of media with circular fibers (see [5] for a review). In almost all these models, pressure drop across a medium is presented as a function of fiber diameter d_f and Solid Volume Fraction (SVF) α:

$$\frac{\Delta p}{t} = f(\alpha)\frac{4\mu U}{d_f^2} \tag{1}$$

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