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Modeling service life of pleated filters exposed to poly-dispersed aerosols

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ABSTRACT

In this work, we present a fast and flexible 3-D macroscale simulation method for modeling the instantaneous pressure drop and collection efficiency of pleated fibrous filters when exposed to poly-dispersed aerosols in both surface and depth filtration regimes. The simulations are conducted using the Fluent CFD code enhanced with a series of in-house subroutines. A cluster-injection method is developed to accelerate the formation and growth of dust-cake both inside and outside the filter media. Once calibrated with experiment or more accurate microscale simulations, the cluster-injection method can be used to simulate the service life of a pleated filter with reasonable accuracy and CPU time. The simulation methodology developed in this work can be used to design and develop pleated filters for different applications. In particular, it allows one to study the effects of pleat shape, pleat count, filter porosity, fiber diameter(s), flow velocity, aerosol concentration, and particle diameter, as well as the aerodynamic parameters of the flow on the evolution of a filter's pressure drop and collection efficiency over time. For demonstration purposes, performance of an arbitrary filter with 2 and 4 pleats per inch is simulated when challenged with poly-dispersed particles of 1 to 10 μm in diameter. For the filter simulated here, it was found that exposure to the above poly-dispersed aerosols results in a shorter service life in comparison to when the filter is exposure to mono-dispersed aerosols with a diameter of 1 or 10 μm having the same mass flux.

1. Introduction

Pleated filters are used in a variety of applications whenever the available space to accommodate a flat-sheet filter is limited, such as in engines or HVAC systems. Understanding the air flow pattern in a pleat channel is essential for designing pleated filters with life-long optimum performance. The air flow pattern in a pleated filter depends on the pleat geometry (and pleat count), properties of the fibrous media, and the aerodynamic conditions of the flow. In addition, the flow field depends on the dust deposition pattern in the pleat channel. The latter itself is a function of the factors listed above as well as the properties of the particles. Given the large number of parameters influencing the performance of a pleated filter, developing a computational method that takes all these parameters into account becomes the natural course of action in design and manufacture of pleated filters in this day and age where high-speed computers are becoming readily accessible. The motivation for the study presented here is to provide a fast and flexible mathematical method for virtually testing the design of a pleated filter for its life-long performance before it is actually manufactured. This can help to reduce the manufacturing cost of new pleated filters by minimizing the number of required experimental trials.

Published studies on modeling performance of pleated filters date back to the pioneering works of Chen et al. [1] and Lucke and Fissan [2] in which the flow of air in pleated filters was simulated with the aim of optimizing the pleat count for minimizing the pressure drop in the absence particle loading. Simulations of air flow in clean pleated filters have also been reported for different radial or flat filters for different applications [3–7]. Past studies to numerically simulate dust-loaded filters were mostly focused on modeling dust deposition on a single fiber, and somehow using the results to predict the performance of the whole filter (i.e., an assembly of a large number of disordered fibers each experiencing a different aerodynamic/loading condition). Such studies have been reported in many pioneering works firstly by Payatakes and Tien [8] and then by many others, each contributing to the state of the art in modeling dust-loaded single fibers [9–16]. While very important in understanding the physics of particle capture, the results of single fiber simulations cannot be used to produce accurate predictions for the performance of a fibrous filter. In this concern, we developed a microscale 3-D simulation method to predict the instantaneous pressure drop and collection efficiency of fibrous media under particle loading [17]. Unfortunately, microscale 3-D simulations are computationally very expensive (the term microscale simulation is used here to refer to simulations on scales comparable to the diameter of the fibers). With the current computational power, it is practically impossible to devise a 3-D microscale simulation to model the deposition of aerosol particles in a pleated filter. Therefore, we have been developing macroscale

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