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Short Communication

3-D microscale simulation of dust-loading in thin flat-sheet filters: A comparison with 1-D macroscale simulations

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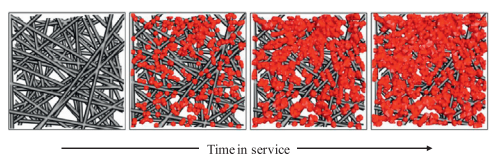
HIGHLIGHTS

- An accurate computational method is developed for modeling filter aging.
- The rate of increase of pressure drop and capture efficiency is predicted.
- A comparison is made between 3-D microscale and 1-D macroscale simulations.
- Pros and cons of 3-D microscale and 1-D macroscale simulations are discussed.
- Reasonable agreement with published experiments is observed.

GRAPHICAL ABSTRACT

An example simulation of particle deposition on a virtual fibrous medium over time. Fibers and particles are 1 μm in diameter.



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ABSTRACT

In this work, a microscale approach is undertaken to simulate the instantaneous pressure drop and collection efficiency of fibrous media exposed to particle loading, i.e., filter aging. The air flow field through 3-D disordered geometries representing the internal microstructure of a fibrous filter is obtained by numerically solving Stokes' equations. A Lagrangian approach is used to track the trajectory of particles through our virtual filter media and determine the filter's collection efficiency under different dust-load conditions. The calculations were conducted using the ANSYS CFD code enhanced with a series of in-house C++ subroutines. To better illustrate the value of such CPU-intensive 3-D microscale modeling, we compared the results of our simulations with those obtained from a 1-D macroscale model developed based on some of the pioneering studies reported in the literature. It was found that while the 1-D macroscale models can provide fast predictions for the pressure drop and collection efficiency of a given filter, they require a series of empirical correction factors or case-specific assumptions that limit their usage for design and development of new filter media. The 3-D microscale simulation methods, in contrast, are self-sufficient as they are developed based on first principles. With the current rate of progress in developing high-speed computers, it is expected that 3-D microscale simulations will be the preferred method of filter design in the near future.

1. Introduction

Fibrous materials are the most commonly used means of particle filtration. The theory of particle filtration was originally developed for a single fiber (the single fiber theory) and later extended to also include the effects of neighboring fibers (see the books of Brown (1993), Spurny (1998), Tien (2012) for comprehensive reviews of the filtration literature). These theories have originally been developed using an exact or a numerical solution of the flow field around perfectly clean fibers placed normal to the flow direction in a 2-D ordered configuration (i.e., lattice). Obviously, deposition of filtered particles leads to the formation of complicated dendrites on the surface of the fibers, altering the flow field inside a filter, and thereby affecting its pressure drop

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