Separation and Purification Technology 98 (2012) 344–355

Contents lists available at SciVerse ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

A macroscale model for simulating pressure drop and collection efficiency of pleated filters over time

S. Fotovati [a], H. Vahedi Tafreshi [a,*], B. Pourdeyhimi [b]

[a] Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, Richmond, VA 23284-3015, United States
[b] Nonwovens Cooperative Research Center, The Nonwovens Institute, NC State University, Raleigh, NC 27695-8301, United States

ARTICLE INFO

Article history:
Received 14 December 2011
Received in revised form 15 June 2012
Accepted 10 July 2012
Available online 20 July 2012

Keywords:
Modeling filtration
Pleated filters
Dust-load simulation

ABSTRACT

In this work, a computationally affordable macroscale model is developed to simulate the instantaneous collection efficiency and pressure drop of pleated depth filters. The numerical scheme presented here allows for the deposition of particles inside the fibrous fabric of a pleated filter, and accordingly varies its permeability and capture efficiency to simulate aging of the filter over time. This has been accomplished by developing a series of in-house subroutines that remarkably enhance the capabilities of the commercially available computational fluid dynamics code from ANSYS. This model is used to quantify the influence of pleat count, particle diameter, and flow velocity on the instantaneous performance of pleated filters with V-shaped pleats. Our results indicate that increasing the number of pleats reduces the rate of increase of a filter's pressure drop and capture efficiency. Predictions of our model have been compared against available experimental data, and good agreement has been observed.

1. Introduction

In principle, pressure drop and particle collection efficiency of a pleated filter depend on two contributing factors. The first, and most prominent, is the fibrous medium itself, and the second, which is often underestimated, is the pleat geometry. The general consensus in designing pleated fibrous filters in industry is that a filter's collection efficiency is independent of its pleat shape or pleat count, and filter designers often optimize the pleat geometry only to minimize the filter's pressure drop. This approach is quite suitable for designing HEPA filters, where the filter media have very high particle collection efficiency. However, when a filter's particle collection efficiency is much less than hundred percent, like in the case of pre-filters or auxiliary filters used in residential buildings, the pleat geometry can significantly influence the collection efficiency of the filter, especially when the filter becomes loaded with deposited particles over time. To the knowledge of the authors, there are no criteria for designing pleat shape and pleat count for optimizing both the pressure drop and collection efficiency. More importantly, the influence of particle loading (i.e., filter aging) on performance of fibrous filters has never been studied in the past, except for our own work, in which the effects of micron-sized dust deposition on pressure drop of HEPA filters were simulated [1]. The objective of the current paper, therefore, is to develop a methodology for predicting the effects of pleat shape on both instantaneous pressure drop and instantaneous collection efficiency of a filter.

The first numerical simulation to study the effects of pleat geometry on performance of a fibrous filters dates back to 1995, when Chen et al. [2] calculated the pressure drop across clean fibrous filters with rectangular pleats, and showed that there exists an optimum pleat count at which the pressure drop of a clean pleated filter reaches a minimum. Since the work of Chen et al. [2], only a few other investigations have been reported in the literature with regards to the effects of pleat geometry on performance of a filter [3–11]. None of the above studies, however, included the effects of particle loading in their pleat optimization. As mentioned before, the only available publication in which particle deposition is taken into account in developing guidelines for pleat shape optimization, is that of Fotovati et al. [1]. The simulations of Fotovati et al. [1], however, were only appropriate for HEPA filters, as the influence of pleat shape or dust deposition on collection efficiency was neglected. This restriction is relaxed in the current study, thanks to a new modeling concept that we have developed for inclusion of particle deposition inside the fibrous structure over time, and simulation of instantaneous performance of the filter. This has been made possible by developing a CPU-friendly macroscale model that treats the fibrous structure of a filter as a porous medium with varying permeability and collection efficiency. As will be seen later in the paper, some of the expressions for the pressure drop or collection efficiency calculations are taken from the literature for the sole purpose of model development (see

* Corresponding author. Tel.: +1 804 828 9936.
E-mail address: htafreshi@vcu.edu (H.V. Tafreshi).
URL: http://www.people.vcu.edu/~htafreshi/ (H.V. Tafreshi).

1383-5866/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.seppur.2012.07.009