Chemical Engineering Science 66 (2011) 4036–4046

Contents lists available at ScienceDirect

Chemical Engineering Science

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

Modeling instantaneous pressure drop of pleated thin filter media during dust loading

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

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

ARTICLE INFO

Article history:
Received 28 March 2011
Received in revised form
18 May 2011
Accepted 20 May 2011
Available online 31 May 2011

Keywords:
Aerosol
Filtration
Fluid mechanics
Porous media
Separation
CFD simulation

ABSTRACT

In this paper, we present a modeling methodology for studying the effects of dust loading on the pressure drop across pleated filters. Our simulations demonstrate that there exists an optimum pleat count for clean filters at which pressure drop reaches a minimum regardless of the in-plane or through-plane orientation of the fibers. With the particle deposition included in the analysis, our results indicated that the rate of increase in pressure drop decreases with increase in the pleat count. We demonstrated that a higher pleat count results in a higher flow velocity inside the pleat channels causing more non-uniformity in the dust deposition across the pleat. Especially when particles are sufficiently large, the dust cake tends to form deeper inside the pleated channel when the pleat count is high. This effect is observed to be less pronounced when the pleats have a triangular shape. We also showed that if the dust cake permeability is higher than that of the filters fibrous media, the rate of increase in pressure drop does not always decrease with increase in the pleat count. Finally, by comparing filters having 15 pleats per inch, we observed that rectangular pleats are preferred over the triangular pleats when the particles are highly inertial, i.e., filtering high-speed large particles. When particle's inertia is small, our results indicate that triangular pleats cause less pressure drop, and so are recommended.

1. Introduction

Almost all existing theories of aerosol filtration are developed for flat media placed perpendicular to the air flow direction. These theories have resulted in a series of semi-analytical expressions derived for calculating filter collection efficiency and pressure drop, which have been widely used to design flat panel air filters. Most filters, however, are made of pleated media. Expressions for flat filters do not provide any information directly useful for designing pleated ones. Most of the progress made in developing pleated media has therefore been based on empiricism.

Pressure drop across a pleated filter is caused by two equally important factors. The first and most obvious contributor in the filter's pressure drop is the fibrous medium. The second contributing factor is the pleat geometry. In a pioneering work, Chen et al. (1995) modeled the pressure drop across clean filters with rectangular pleats using a finite element method and discussed the influence of the above factors in a filter's total pressure drop. These authors also showed that increasing the pleat count increases the pressure drop due to the geometry but decreases that caused by the fibrous media. Therefore, there exists an optimum pleat count at which the total pressure drop of a clean pleated filter is minimum. To the knowledge of the authors, there are only very few studies in the literature dedicated to studying the influence of pleat geometry, and almost all of them neglect the effects of dust deposition on pressure drop (Chen et al., 1995; Lucke and Fissan, 1996; Del Fabbro et al., 2002; Caesar and Schroth, 2002; Subernat et al., 2003; Tronville and Sala, 2003; Wakeman et al., 2005; Waghode et al., 2007; Lo et al., 2010; Rebai et al., 2010). Dust deposition can adversely affect the performance of a filter over time, and surprisingly, it has not yet been included in the theories developed for filter design. Therefore, the objective of our current study is to investigate the influence of particle deposition on the rate of pressure drop increase in filters with different pleat geometries.

In the remainder of this paper, we first discuss the fibrous media and the pleat geometries (rectangular and triangular) considered for this study along with the governing equations and numerical scheme considered for simulating air flow field inside pleated filters in Section 2. The algorithm for tracking dust particles and modeling their deposition is discussed in Section 3. Performance of filters with different pleat geometries under different levels of dust-load, are discussed in Section 4. In this section we also study the effects of particle size and flow velocity of the rate of pressure drop increase, and present a comparison between filters with rectangular and triangular pleats. This section is followed by our conclusions summarized in Section 5.

* Corresponding author. Tel.: +1 804 828 9936; fax: +1 804 827 7030.
E-mail address: htafreshi@vcu.edu (H. Vahedi Tafreshi).

0009-2509/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2011.05.038