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An analytical approach to predict pressure drop and collection efficiency of dust-load pleated filters

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ABSTRACT

In this work, a series of first-principle analytical expressions are derived to predict the instantaneous pressure drop and collection efficiency of pleated filters under dust loading condition. Both the depth and surface filtration regimes are formulated for filters with triangular and rectangular pleats. The analytical expressions derived in this paper can be used in the early stages of designing a pleated filter to circumvent the need for conducting CPU-intensive numerical calculations. The predictions of our analytical expressions are compared with those reported in previous studies and good agreement is observed.

1. Introduction

Pressure drop and collection efficiency of a pleated filter depend on a number of parameters including, but not limited to, pleat geometry, flow properties, fiber diameter(s), filter porosity, and particle inertia. In addition, the particle deposition pattern in the pleat channel or inside the fibrous structure of the filtration media can greatly affect the filter's overall pressure drop and collection efficiency. Accurate prediction of the instantaneous performance (i.e., pressure and collection efficiency) of a pleated filter in service requires CPU-intensive parallel computation. In a previous study, we developed a microscale simulation method (i.e., simulations on scales comparable to the fiber diameter) that could predict the pressure drop and collection efficiency of a dust-loaded fibrous sheet without requiring any empirical correction factors [1,2]. This CPU-intensive simulation method was then modified to make it applicable to simulation domains as large as a pleat channel, and was referred to as the macroscale simulation method [3–5]. The macroscale simulations are significantly faster than their microscale counterpart; however, they need to be calibrated using experiment or computational data generated by a more accurate simulation method (e.g., microscale simulations). To further reduce the computational cost of designing a pleated filter, we recently developed a semi-numerical method that could be considered "CPU-independent" in terms of calculation time [6,7]. This was thanks to the empirical correlations that were used to describe the velocity field in the simulation domain, leaving only the particle trajectory calculations to be carried numerically by the semi-numerical model.

Using the information obtained from the above-mentioned simulations with regards to dust-cake growth patterns inside a pleated filter, the current paper presents a novel set of analytical expressions that can be used to predict the instantaneous performance of a pleated filter during its service life without the need to use a computer. This is achieved by determining the independent variables that affect the performance of a pleated filter, and by grouping them together in such a way that they can be related to the filter's pressure drop and collection efficiency (dependent variables). Our work also takes advantage of the findings of many pioneering studies reported in the literature (see e.g., [8–17]).

In the following sections, we first focus on dust-loaded pleated filters with triangular pleats in the depth filtration regime—the regime in which particles deposit inside the fibrous media—and derive predictive expressions for their pressure drop and collection efficiency (Section 2). We then extend our formulations to also develop such expressions for pleated filters operating in the surface filtration regime, i.e., filters which do not accommodate depth deposition (Section 3). These formulations are then modified for when the pleated geometry is formed into a circular shape (Section 4). Studies similar to those presented in Sections 2 and 3 are presented in Sections 5 and 6, respectively, for filters with rectangular pleats. Comparisons with experiment and our previous macro-scale models are presented in Section 7. The conclusions drawn from our work are given in Section 8.

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