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Short Communication

Service life of circular pleated filters vs. that of their flat counterpart

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ABSTRACT

In this note, an easy-to-use two-dimensional model is developed to predict the instantaneous pressure drop and collection efficiency of circular pleated filters as a function of time in both the surface and depth filtration regimes. Our model uses average velocity profiles that represent the flow field inside a circular pleated filter to circumvent the need for conducting CPU-intensive CFD calculations to predict the service life of a circular filter. This is accomplished by considering a reasonable dust-cake profile inside the pleat channels as a function of the flow and particles properties, and allowing the cake to grow as the filter continues to collect particles over time. Despite the approximate nature of its predictions, the speed at which a large parameter study can be completed makes the present model very valuable for design and development of circular pleated filters. Using this model for instance, it can be shown quantitatively that circular filters with high inlet-to-outlet diameter ratios outperform their flat counterparts.

1. Introduction

Aerosol filters are often pleated into triangular or rectangular patterns and the resulting geometries are often rolled up into a circular shape to accommodate as much filtration media as possible in a confined space (see Fig. 1a). Obviously, the inlet and outlet diameters of the pleats depend on the dimensions of the casing in which the circular cartridge will be placed. Despite the widespread use of pleated filters, the effects of dust deposition and cake formation on the performance of such filters have only been reported in a very few studies (e.g., the computational studies in [1–5] or the experimental work in [6–11]). As such, no study has yet been reported to establish a link between the radial geometry of a circular pleated filter and its filtration performance (collection efficiency and pressure drop) when loaded with dust particles. This paper is therefore devised to study the effects of geometric parameters on the filtration performance of circular pleated filters over time. From the basic principles of fluid dynamics, one expects the flow field inside a circular pleat to be different from that of a flat pleat (flow into a sink versus a uniform flow). Therefore, the current work is particularly focused on the differences between the performance of a circular pleated filter and its flat counterpart (see Fig. 1a and b), as pleated fibrous media are often tested in a flat configuration. The present study builds on the in-depth knowledge obtained from our previous computational fluid dynamics (CFD) simulations of dust-cake growth inside pleated filter media in a flat configuration [2–4]. However, in contrast to such CFD simulations, the approximate model presented in this paper allows one to simulate the entire lifecycle of a filter in a few minutes.

In the remainder of this paper, we first present our formulations for predicting the pressure drop and collection efficiency of circular pleated filters with and without dust-cake (Section 2). In Section 3, we compare the predictions of our model to those obtained from more accurate CFD simulations. Our results and discussion are given in Section 4 followed by our conclusions in Section 5.

2. Modeling circular pleated filters

2.1. Clean fitters

Assuming filter media to be the sole source of pressure drop in a pleated filter, the face velocity (air velocity normal to the media) can be obtained using Darcy's law:

$$v_w = \frac{\Delta p}{t_m}\frac{k}{\mu} \tag{1}$$

where Δp is the pressure drop across the media, k is the permeability of the media, t_m is the thickness of the fibrous media, and μ is the air viscosity. Considering a control volume inside the pleat channel,

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Nomenclature

c^c	slip correction factor
d	diameter (m)
h	pleat height (m)
k	air permeability (m^2)
k_c	air permeability in granular media (m^2)
l	pleat length (m)
m	mass per unit fiber length (μg/m)
p	pressure (Pa)
P	penetration
R_{io}	inlet to outlet pleat ratio
t	time
t_m	thickness of fibrous media
τ	relaxation time
u	axial air flow velocity ($m\,s^{-1}$)
u_p	particle axial velocity ($m\,s^{-1}$)
v	vertical air flow velocity ($m\,s^{-1}$)
v_p	particle vertical velocity ($m\,s^{-1}$)
v_r	radial component of flow velocity ($m\,s^{-1}$)
v_w	filtration velocity (m/s)
v_θ	tangential component of flow velocity ($m\,s^{-1}$)
w	pleat wall length (m)
Δp	pressure drop (Pa)
β	flow resistance through porous media
ε	porosity
ϕ	solid volume fraction
δ	cake thickness
θ	angle measured from the center of the radial pleated filter
γ	half-pleat angle
ρ	density ($kg\,m^{-3}$)
μ	air viscosity ($kg\,m^{-1}\,s^{-1}$)
χ	curve fit parameter for the velocity

Superscript

c	Cunningham
p	particle

Subscripts

0	clean fiber situation
e	pleat end
i	pleat inlet
o	pleat outlet
f	fibers
p	particle
w	water

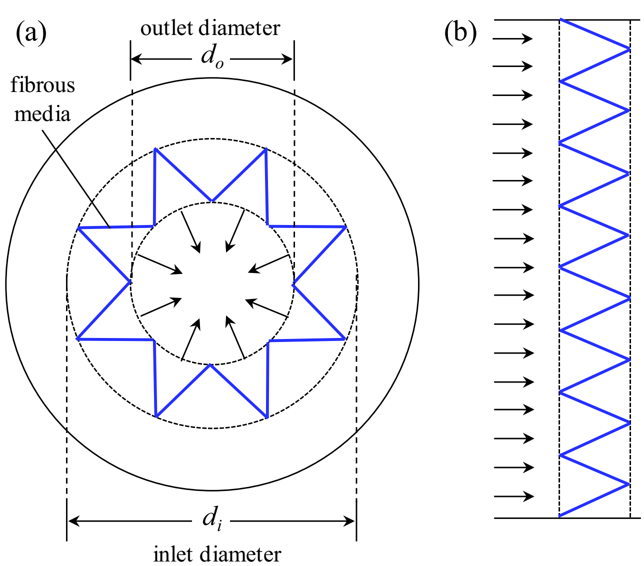

Fig. 1. Circular pleated filter (a); flat pleated filter (b).

the conservation of mass can be used to develop a relationship between the face velocity v_w and the inlet velocity U_i,

$$U_i s_i = v_w w \tag{2}$$

where s_i is the arc length at the inlet, and w is the length of the pleat's fibrous wall, as shown in Fig. 2a. On the basis our CFD observations of the velocity field inside a pleat channel (see the next section), the face velocity over w is assumed to be constant in our formulation. The average radial velocity $\overline{v_r}(r)$ can also be obtained using the conservation of mass,

$$\overline{v_r}(r)s(r) = U_i s_i - v_w\left(w - \frac{r\sin\theta_{max}(r)}{\sin\gamma}\right) \tag{3}$$

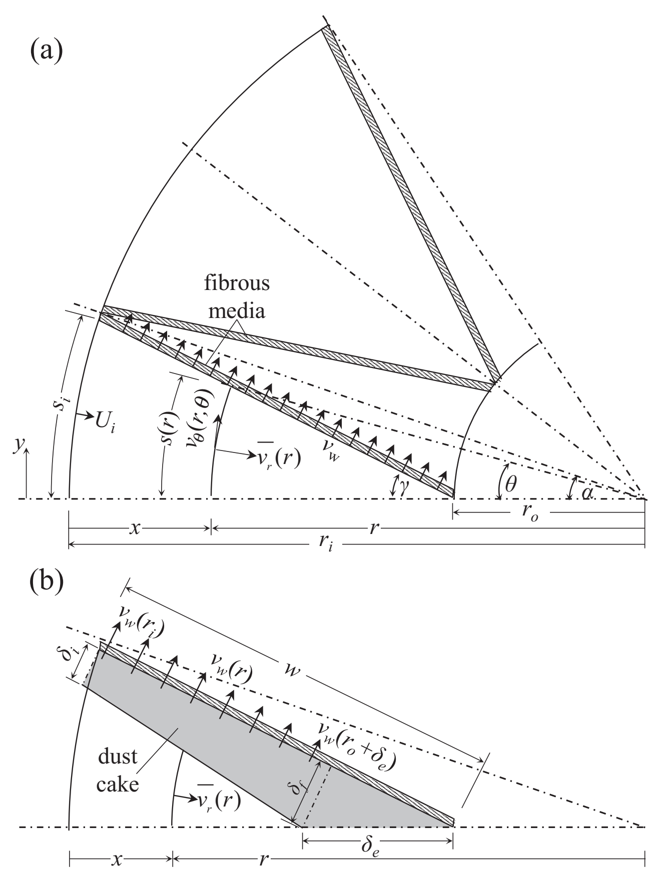

Fig. 2. Computational domain for a clean circular pleat (a) and a circular pleat accommodating a dust-cake (b).

where $s(r)$ is the arc length at any radius $r_o < r < r_i$, $\theta_{max}(r)$ is the angle of the pleat channel at a radius r (measured from the center