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"Gheorghe Asachi" Technical University of Iasi, Romania

VARIETY BEHAVIORS OF DEPTH AND SURFACE FILTER MEDIA WITH THE AGES FOR PLEATED FILTER CARTRIDGES

Yan Cuiping[1,2]*, Liu Guijian[2], Chen Haiyan[1]

[1]*Key Laboratory of Solid Waste Treatment and Resource Recycle, Ministry of Education, School of Environment and Resources, Southwest University of Science and Technology, Mianyang 621010, China*
[2]*CAS Key Laboratory of Crust-Mantle Materials and the Environments, School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China*

Abstract

The aim of this study is to investigate a variety behaviors of two kinds of media (multiple-layer structures and multiple-layer structures combined with surface treatment, such as finer fibers) with ages using a scanning electron microscope (SEM) and to determine the effect of fabric microstructures on cake formation and pulse cleaning. The results show that fine particles are readily deposited on the surface and inside depth filter medium. The fine fibers with diameters (~0.08 microns, this value is smaller than 0.5 microns) are readily sorption the fine particles on the fibers of surface filter medium. As the filtration progresses, analysis of multiple-layer structure fibers and surface treatment (such as finer fibers) using SEM indicates that dust cake filtration dominates in the end, regardless of what the depth filtration or surface filtration dominant was initially. This phenomenon solves the perplexity of many industry factories that the collection efficiency of surface filtration medium decreases if the polytetrafluoroethene fibers with ages are born off during pulse cleaning. The experiment shows that the depth filter medium with high dust holding capacity and difficult cleaning is suitable to collect the low dust laden gas in a long time operation. The surface fine fibers have the similar function with the formed dust cakes for surface filter medium. The dust cake formation and pulse cleaning for surface filter medium is different from the depth filter medium. The fine fibers on surface filter medium are similar to the formed cakes on depth filter medium. The surface filter medium is suitable to recover high dust concentration and fine particles from the dust-laden gas in an on-line operational system.

Keywords: variety behaviors, fine particles, depth filter medium, surface filter medium

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1. Introduction

Fiber filtration is a cost-effective scavenger for fine particulates, and may help prevent their emissions from escaping into the ambient environment (Steffens and Coury, 2007a, 2007b; Yan, et al., 2018). Among all types of fabric filters, bag filters are most widely used for gas-solid separation, since they are low in cost, easy to use and highly efficient in collecting particles (Saleem et al., 2012; Tanabe et al., 2011). Recently, the use of pleated filter cartridges in dust collectors has attracted much attention due to their larger filtration surface as compared to flat-sheet bag filters (Andersen et al., 2016; Bémer et al., 2013; Lo et al., 2010; Zhang et al., 2018). However, the filter dust cake is a source of increasing pressure drop, especially when the filter media are loaded with high concentrations of sub-micron particulates (Lee et al., 2008). High particulate collection efficiency and low-pressure drop are critically important for the application of dust collectors (Li et al., 2018; Samirys et al., 2017). Therefore, a filter has to be removed either at an upper pressure drop limit or at a predefined time interval. Inefficient filters are always associated with short filtration and cleaning intervals, which is generally related to incomplete cake detachment or

* Author to whom all correspondence should be addressed: e-mail: cuipingy_2004@163.com; Phone: +86 13795774342

patchy cleaning (Kavouras and Krammer, 2005; Mao et al., 2008; Saleem and Krammer, 2007). Previous studies have shown that the physical and chemical properties (e.g. fabric microstructure) of filter media are the dominant factors to control cake formation and detachment (Qian et al., 2015). The mechanisms of cake formation and detachment of different fabrics are quite different (Hasolli et al., 2013; Höflinger et al., 2007). Humphries and Madden tested nine different fabric filters to demonstrate the influence of the fabric structure on the pulse cleaning efficiency (Humphries and Madden, 1983). According to Mauschitz et al. (2005) the surface treatment of filter media prolonged the filtration period and reduced the pressure drop after pulse cleaning. Rodrigues et al. (2005) showed that surface treatment of filter media afforded in increased particle collection efficiency and a reduced residual pressure during the filtration. Binnig et al. (2009) showed that the cleaning intensities were related to permeability of filter media. The above results show that the microstructures of the filter media have a profound effect on cake formation and detachment, even in apparently similar fabrics (Tanabe et al., 2011). However, the microstructure variety behaviors of filter media with ages are rarely reported in literatures.

Industrial sectors have been required to comply with stringent air quality regulations to control the emissions of fine particles, especially those with diameters less than 2.5 microns. The presence of the variety behaviors of the filter media with ages has a significant effect on the particle penetration and the particle mass deposited after the cleaning process. With this point in mind, it is critically important to study the variety behaviors of filter media with the ages. In this study, two types of microstructures, i.e. multiple-layer structures and multiple-layer structures combined with surface treatment, were assessed to investigate the cake formation and detachment of the filter cake, providing the filter media for suitable applications.

2. Material and methods

2.1. Filter media

Two types of filter media with different fabric microstructures referred to as filter medium A and filter medium B, were used in the present study. They both consisted of polyethylene terephthalate nonwoven fibers with a diameter of ~15 μm, weight of 260 g/m^2, thickness of 0.6 mm and permeability of 150 L/m ^{2}·s at a 200 Pa pressure drop. In addition, filter medium B contained multiple-layer structures combined with surface treatment. Filter medium B was composed of a layer of polytetrafluoroethene fibers of ~0.08 microns in diameter on a polyethylene terephthalate nonwoven filters substrate composed of ~15 μm in diameter, and permeability of 80-100L/m ^{2}·s at a 200 Pa pressure drop. The detailed characteristics of the filter media were shown in Table 1.

2.2. Fine particles

The particulate matter used in the filtration experiments was Barium sulfate with a diameter of less than 2.5 μm. In the experiments, the Barium sulfate was measured using a Malvern Mastersizer after being processed through a grinder, then a classifier. The particle size distribution of the Barium sulfate was from 0.24 to 1.35 μm. The detailed characteristics of the particulate matter were shown in Table 2.

2.3. Experimental method

First-used and aged filter media were used to collect dust particles to test the variety behaviors of two types of fabric microstructures. The selected filter media were first-used and the ages with one month and one year for depth filtration (multiple layer structure), and first-used and the ages with one year for surface filtration (multiple-layer structures and surface treatment, such as fine fibers). The first-used filter media were designed in closed equipment, as shown in Fig. 1. The particles and inlet airflow were fed into an air jet mill and there was a small air classifier to ensure that only fine particles be contained.

The median diameter of the dust particles fed to the filters was 0.78 microns. The filters can be separated into two parts. The two parts were connected using the bolts. The separated location was used to install the filter media. The filter media can be designed to change from filter medium A to filter medium B. In order to test each filter medium in a real dust filtration process, an exhaust system was used. The dust-laden gas pervades into the filter media from the small air classifier induced by fan, and then the dusts were trapped on the filter media.

Table 1. Characteristics of filter media

Parameters	*Unit*	*A*	*B*
[a]Media thickness	mm	0.6	0.6
Specific weight	g/m^2	260	260
[a]Air permeability	1/m^2·s	150	80-100
[b] Fiber diameter	μm	~15	~0.08
[a]Supporting layer		polyethylene terephthalate	polyethylene terephthalate
[a]Surface treatment		no	polytetrafluoroethene fibers

a Provided by the manufacture; b Experimental data from the SEM

Table 2. Characteristics of the particulate matter

Characterization	*Unit*	*Barium sulfate material particulate*
Specific mass	$10^3 kg/m^3$	4.34
Mean volume diameter	μm	0.77
Mean Stokes's diameter	μm	0.78
Specific surface area	m^2/g	1.036
Sphericity		0.89

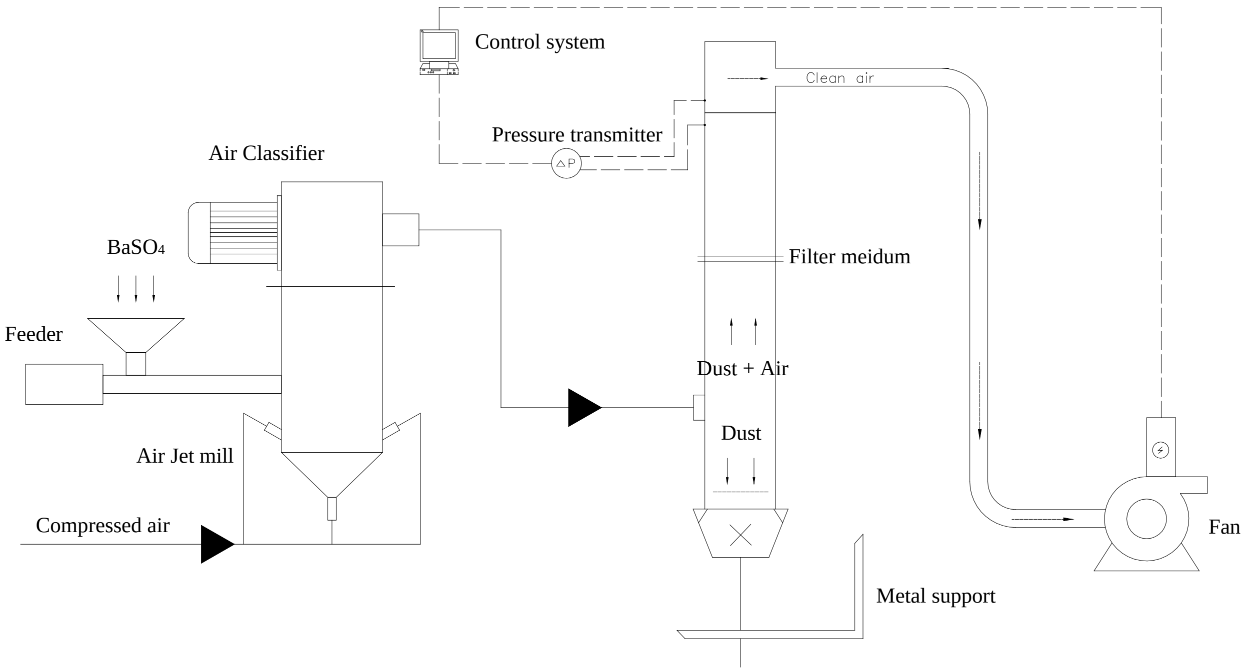


Fig. 1. Experimental process of first-used filter media

Because aged period involved, study of variety behaviors for aged filter media in laboratory was difficult. In order to measure the variety behaviors of the aged filter media, two filter media were designed to filter cartridges. The filter cartridges were used in a dust collector that was used to collect high dust concentration in industrial application. In this paper, the two-dust collector was used in factories. The factory produced types of particles used for food, such as Bracken fern and cuttlefish, and traditional Chinese medicine, such as aloe and Ganoderma lucidum. The two different filter cartridges were used in the same dust collectors with the same dimensions. The two dust collectors were used in two places.

As the same operational time, the filter cartridges were taken out from the dust collector and taken to measure the microstructures using the scanning electron microscope. The sample filter cartridges consisted of the depth filter medium A and surface filter medium B. Fig. 2 shows a schematic view of the test rig (LN5350LT, Mianyang, Liuneng, Powder Equipment Co., Ltd.). Fig. 2 shows that the dimensions of the dust collector compartment were Φ1400×3269 mm. Five filter cartridges were installed in the dust collector. Table 3 shows the filter cartridge dimensions. A rigid wire cage supported the filter medium.

2.4. Measurement of dust location inside the medium

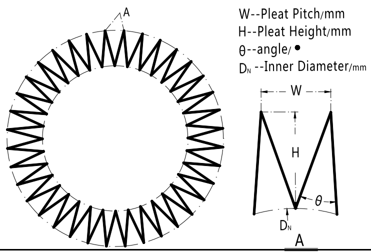
The morphology of the spun fibers and the surface and cross-section of the filter media before and after filtration testing were examined using a Leica 440 scanning electron microscope (SEM). The filter media were taken out from the dust collectors. The filter media were reduced to squares with 2×2 cm. The samples were fixed on the sample tables. The surface microstructures were photographed using the scanning electron microscope. Then, the sample tables were rotated with the 90° and the cross section microstructure were photographed using the scanning electron microscope.

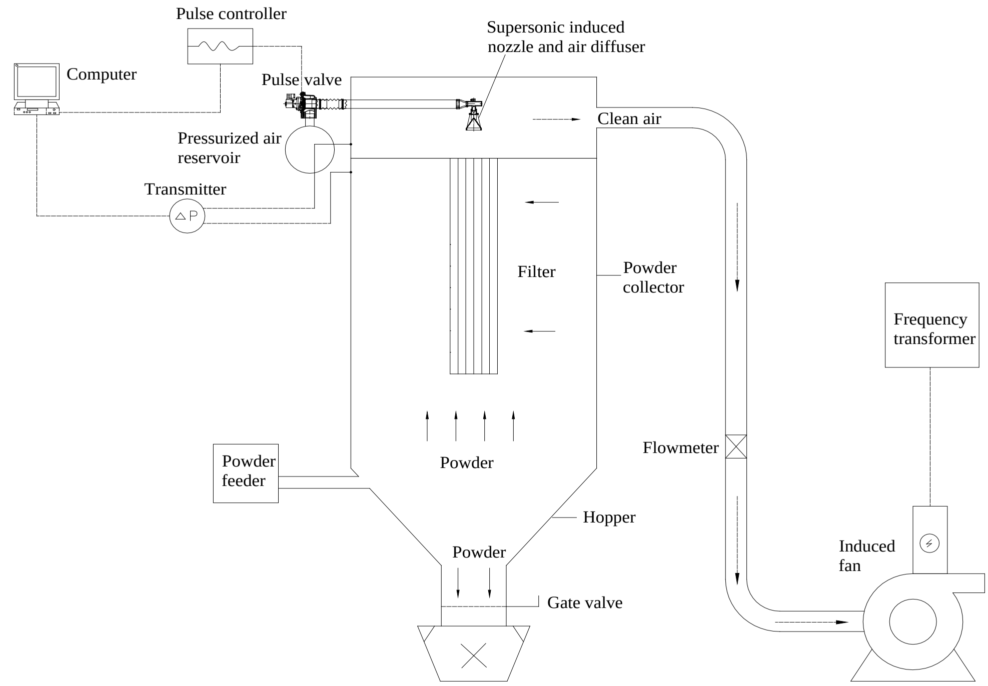
3. Results and discussion

3.1. Behaviors of first-used filter media

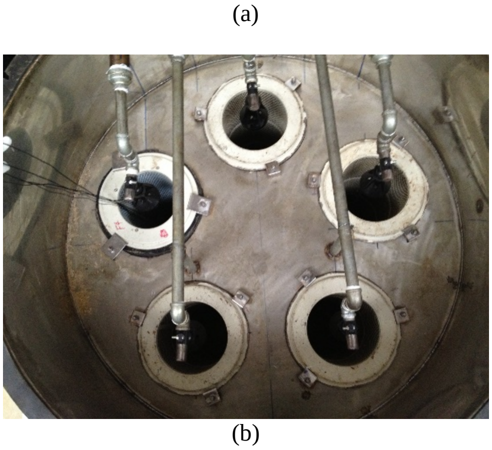
Detailed specifications in the layer structure of both filter media are listed in Table 1. Fig. 3 shows the apparently similar fabrics. Figs. 4 and 5 show the SEM micrograph microstructures of the surface-section and cross-section filter media, where it may be observed that the fabrics show signs of polyethylene terephthalate nonwoven fibers and finer polytetrafluoroethene fibers. The fabric diameter was obtained by analyzing the images from SEM.

Table 3. Experimental equipment dimensions designed for the aged filter media

Parameters	
Pleat number (n)	125
Pleat pitch (W, mm)	8.164
Pleat height (H, mm)	45
Pleat ratio (H/W)	5.5
Inner diameter (D_{in}, mm)	215
External diameter (D_{Ex}, mm)	325
Filter length (L, mm)	1000
Filtration area (A_f, m^2)	11.25*5=56.25
Thickness of filter medium (mm)	0.6
Angle (θ, °)	2.88
Remarks: top view of a pleated filter cartridge	

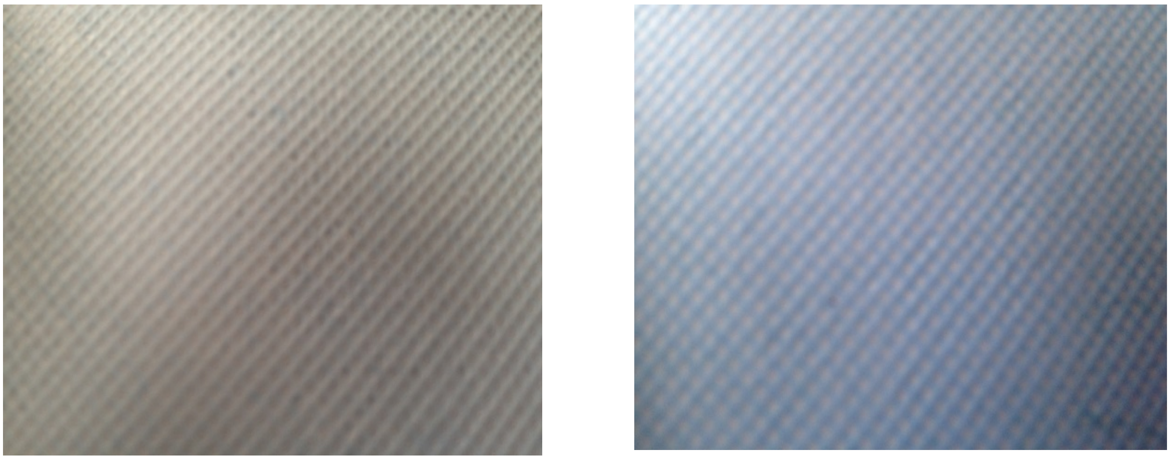


(a)



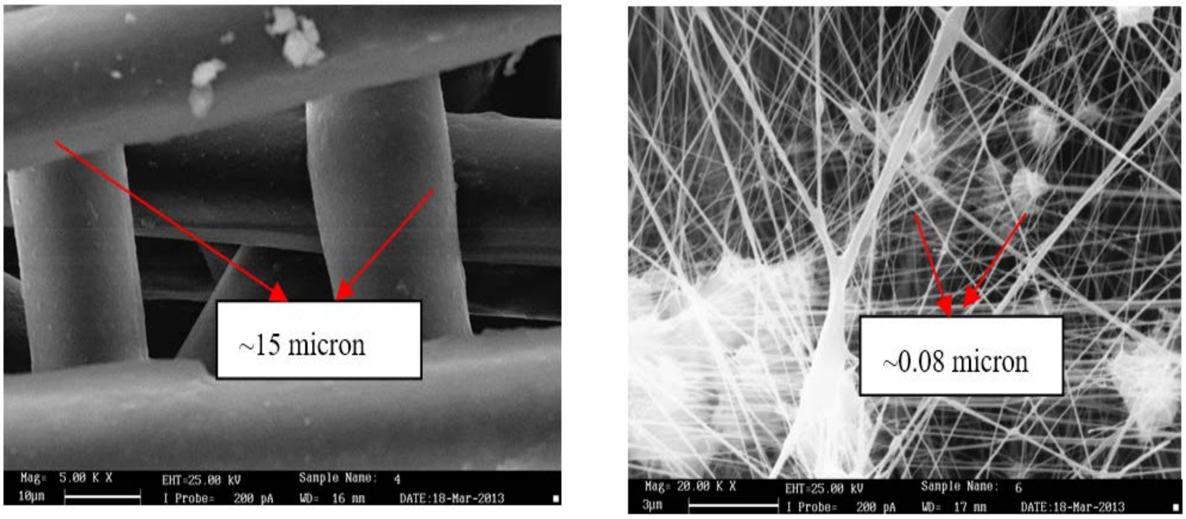
(b)

Fig. 2. Experimental equipment of the aged filter media:
(a) schematic view of the test rig and (b) description of five cartridges



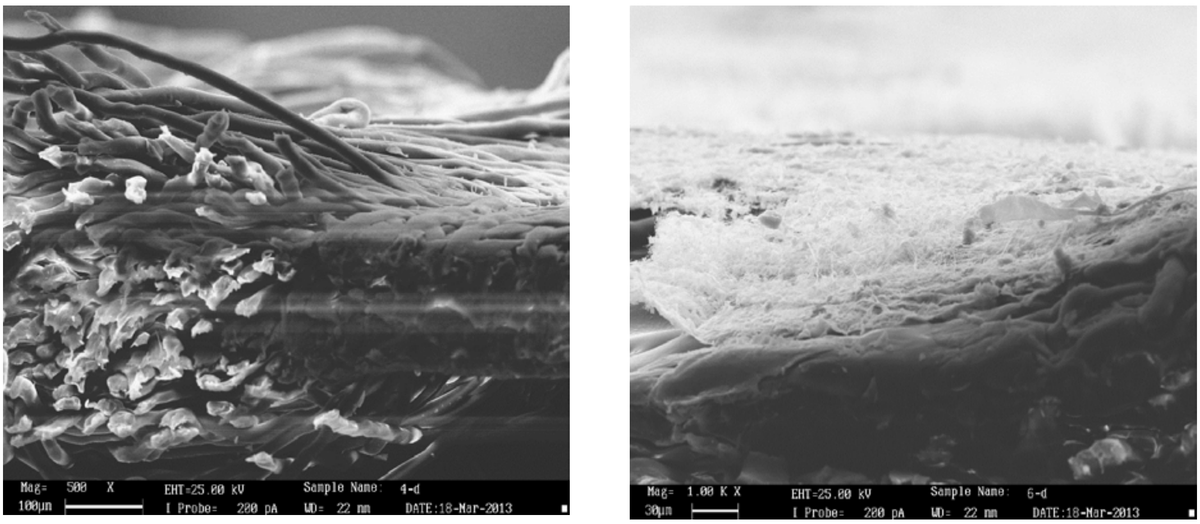
(a) (b)

Fig. 3. Apparently similar fabrics of (a) filter medium A and (b) filter medium B



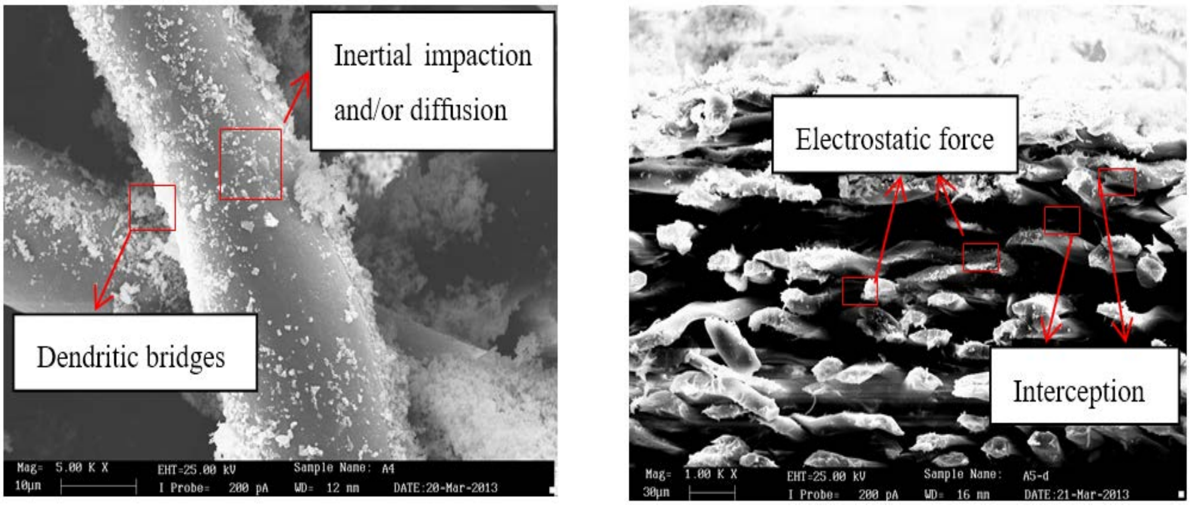
(a) (b)

Fig. 4. Surface microstructure of new (a) filter medium A and (b) filter medium B



(a) (b)

Fig. 5. Cross section microstructure of new A and B filter media: (a) filter medium A and (b) filter medium B



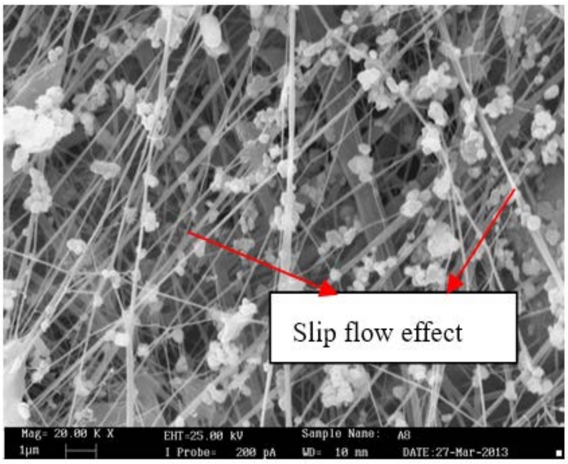
(a) (b)

Fig. 6. Filtration behaviors of first-used filter medium A: (a) surface sorption of filter medium A, (b) sorption and penetration within filter medium A

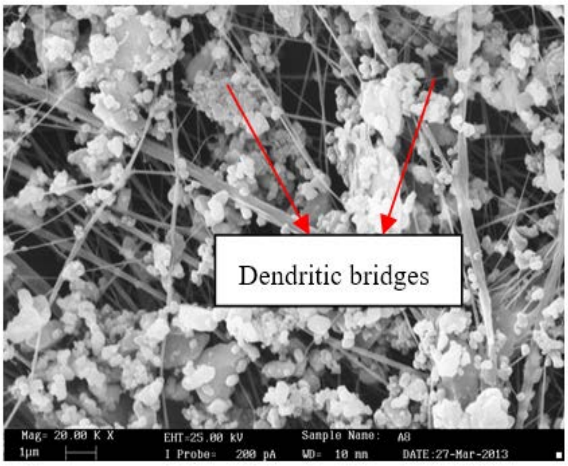
Fig. 6a shows that although the filter pores are larger than the dust particles, the inertial impaction and/or diffusion have forced the particles to be trapped on the fibers through the random flow paths. In addition, inter-particle forces cause the particles to form dendritic bridges, and then clog the filter media. From Fig. 6, it may be seen that very small particles (<0.5 μm) diffuse according to the Brownian (zig-zag) motion. This random and probabilistic motion caused particles to separate from the streamline, and possibly engage on fibers. Electric or electrostatic charges on the particles and/or fiber may force the particles to be diverted from the streamline and attract the particles toward the fibers. This process is defined as depth filtration, and involves difficulty in removing the particles inside the filter media, especially the sorption of Brownian (zig-zag) motion and electric or electrostatic charge. Fig. 6 shows that the dust particles not only sorption on surface, but also pervades to inside depth filter medium. Therefore, the depth filter medium has high dust loading capacity.

Figs. 4b and 5b shows that filter medium B has a multiple layer structure as well as a surface structure. Fig. 4b shows that the surface structure of this medium is made of fine fibers. The diameter of the fine fibers is ~0.08 microns. Fig. 7a shows that the fine particles are only sorption on the finer fibers. Fig. 7b shows that then the inter-particle forces form dendritic bridges and clog the filter media. Therefore, the fine particles are not trapped in the internal filter media. For fibers with diameters smaller than 0.5 microns, slip flow must be considered (Wang et al., 2008; Skomra, 2011; Hutten, 2007). Slip flow may predominate at the fiber surface, which allows more air to travel near the fiber surface. This causes more particles to travel near the filter surface, thus increasing particle capture probability. From Fig. 7, it may be see that the particles were trapped on the fibers, and the effect of slip flow was significant. Fig. 7c shows that the fine particles were trapped on the fine fibers of filter medium B, rather than on the internal media. This result agrees with the observations that show that sophisticated filter surface treatment can improve the filtration performance.

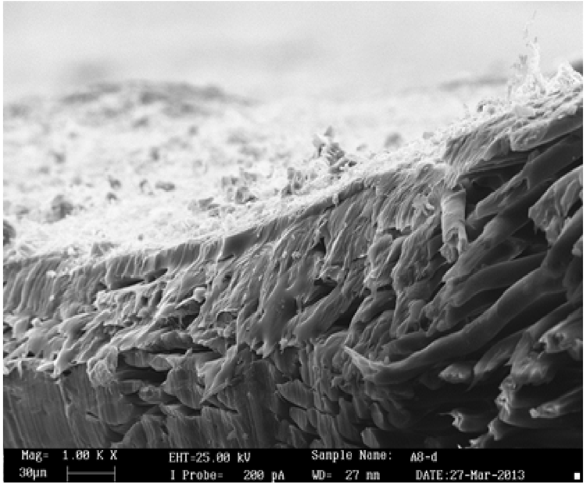
Although the filer medium B with the filter pores are larger than the diameters of particles, the fine fibers with diameters (~0.08 microns) smaller than 0.5 microns are readily sorption on the fibers.



(a)



(b)



(c)

Fig. 7. Filtration behaviors of new B filter media: (a) slip flow effect, (b) dendritic bridges of B filter medium, (c) cross section of B filter medium

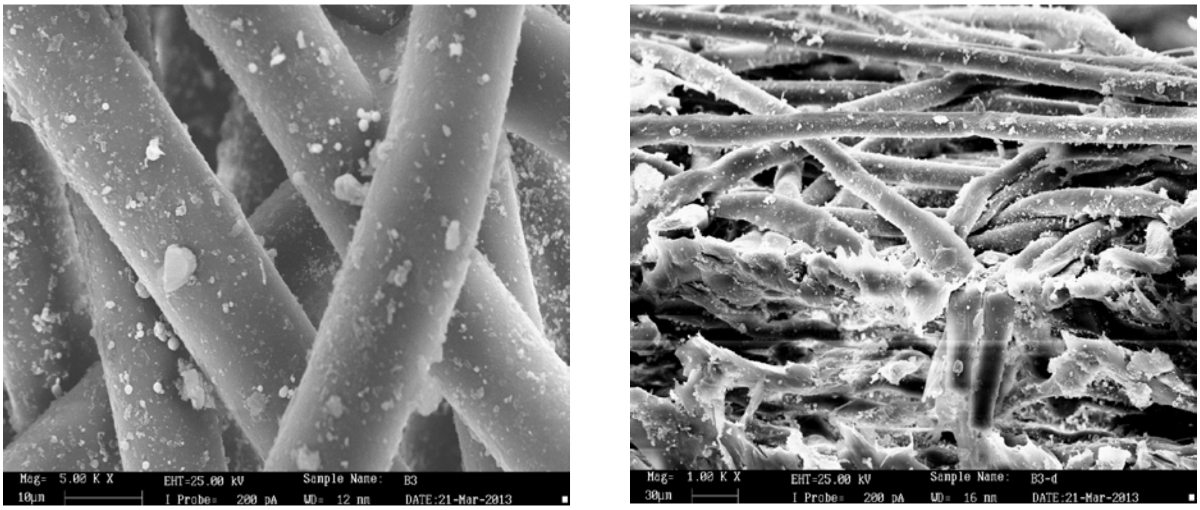
This is different from that the particles are not only deposited into the filter medium A but also onto the surface due to the fact that the particles adhere to the airstreams. As the filtration progresses, the superficial fine fiber layer on the filter medium B is similar to the formed dust cake on the filter medium A. Therefore, the surface filter medium has low dust loading capacity. The experimental result shows that the surface filter medium is suitable to collect the fine particles.

3.2. Filtration behaviors on filter media with ages

Figs. 8 and 9 present the depth filter media with one month and one year of, respectively. The particles are trapped within rather than on the surface of filter media, due to the inertial impaction, interception, diffusion and electrostatic attraction of particles. The dust agglomeration with dendrites play a role in closing the open channels at first, and then the surface filtration dominates. With the proceeding of the filtration, the thickness of the formed cake increased and formed a state dust cake.

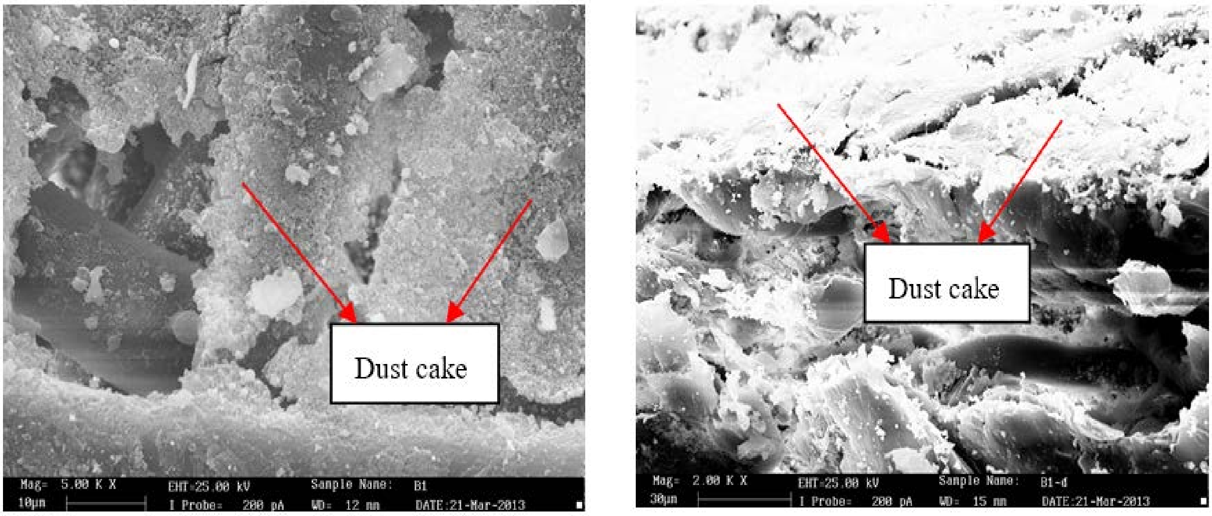
The particles are readily clogged the internal media for the depth filtration, especially when large quantities of ultrafine particles with high clogging capacity are filtered. Particles internal the media could not be readily removed. These results of the depth filtration process agree with the results of Binning (Binnig et al., 2009). It is difficult for the clogging particles to retrieve from the filter media during cleaning. The depth filtration results in clogging of the media. It can be seen from Fig. 8b that the compact layer significantly affected the filtration. The experimental result shows that the cleaning is difficult for depth filter medium.

Fig. 10a shows that the particles are only retained on the surface filter medium B of filter cartridges one-year-used. Fig. 10b shows that the particles did not penetrate through the filter media of the filter cartridges one-year-used. The dust cake gradually plays a role in closing the surface open channels, thus the surface filtration dominates. However, the finer polytetrafluoroethene fibers are not observed in Fig. 10a. The finer polytetrafluoroethene fibers may be born off or form to the total dust cake in a long period of time. In fact, the particles are only retained on the surface of the filter media. Fig. 11 shows that the gradually magnified microstructures of the filter medium B show that the dust cake filtration dominates. The function of dust cake traps the particles as the fibers. In Figs. 8-10, it may be seen that with the proceeding of filtration, the dust cake became compacted, and the actual dust cake retain the particles as the fibers and dominates the filtration process.



(a) (b)

Fig. 8. Filtration behaviors of filter media A with one month: (a) surface of one month used A filter medium, (b) cross section of one month used A filter medium



(a) (b)

Fig. 9. Filtration behaviors of filter media A with one year used: (a0 surface of filter medium A with one year, (b) cross section of filter medium A with one year

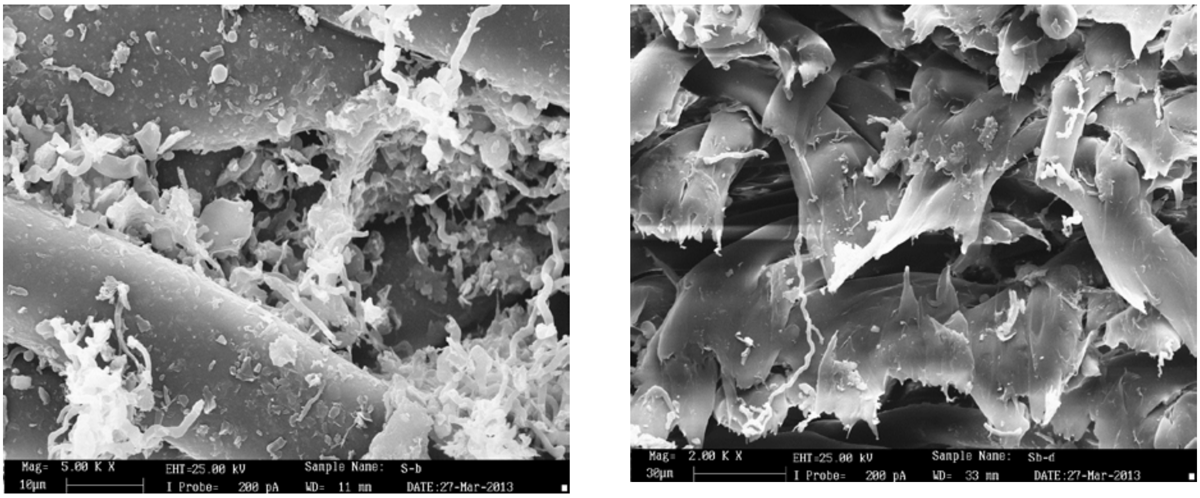
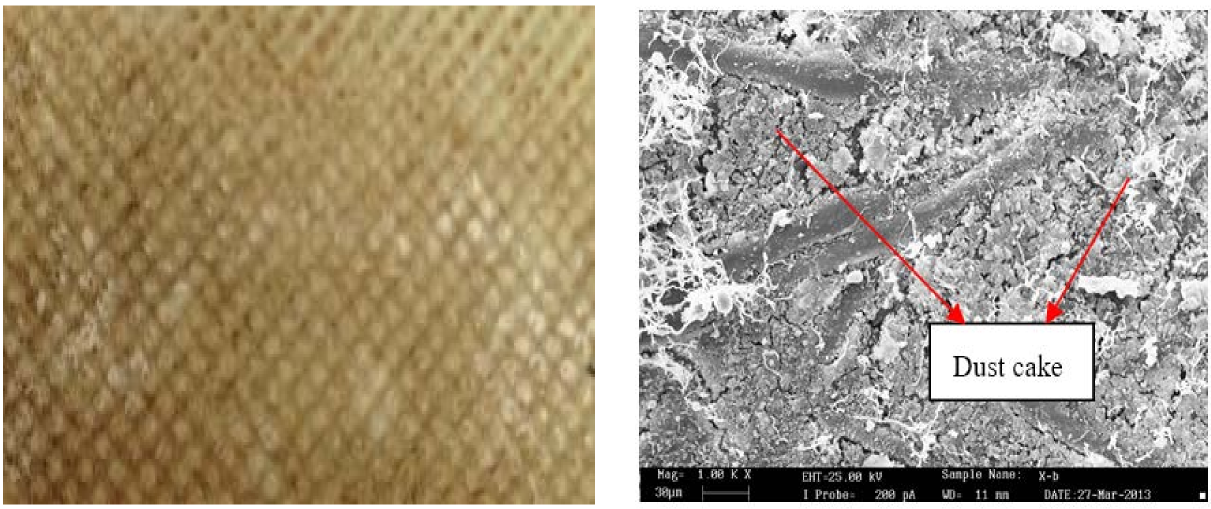


Fig. 10. Filtration behaviors of filter media B with one year used: (a) surface of filter medium B with one year, (b) cross section of filter medium B with one year



(a) (b)

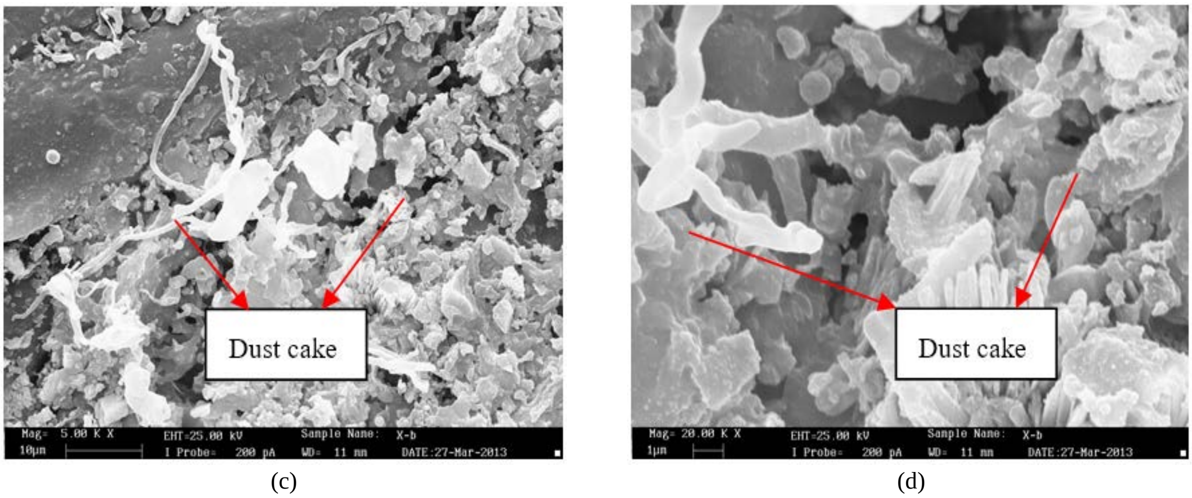


Fig. 11. Dust cake effect: (a) photo of B filter medium, (b) 1000 x of B filter medium, (c) 5000 x of B filter medium, (d) 20000 x of B filter medium

As the filtration progresses, the dust cake is formed on the surface of filter medium B and appears a steady cake. The particles are not opportunities into inner pores of the filter medium B. However, the particles go into the pores of filter medium A and clog the pores among the fibers. In some cases, the dust cake is formed on the filter medium A and gradually appears a steady state. Under this condition, the particles are not readily into the pores of filter medium A. Finally, the formed dust cake, regardless of the initial the depth filtration or surface filtration, filters the dust laden gas. This phenomenon solves the perplexity of many industry factories that the efficiency of filter medium B decreases if the polytetrafluoroethene fibers with ages are born off during pulse-jet cleaning.

3.3. Effects of aged filter cartridges on pressure drops

From Figs. 12 and 8b, it can be seen that at the first filtration time, the dust holding capacity of filter medium A greatly increases the pressure drop for the depth filtration.

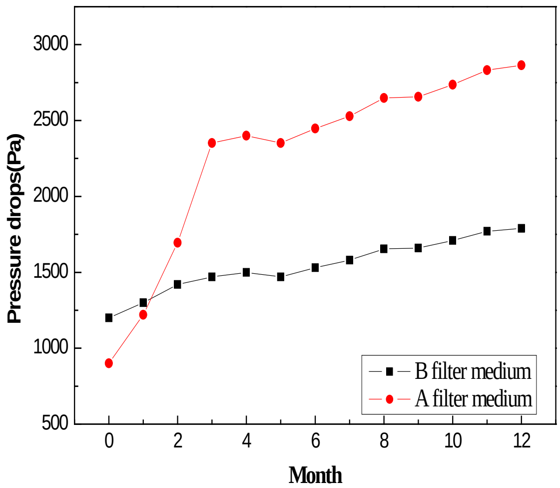


Fig. 12. Pressure drops of A and B filter media via time

As the filtration progresses, the formed compact cake predominates the filtration process. The pressure drop remains steady. From Figs. 12 and 9b, it can be seen that the increase of the pressure drop of filter medium B is less steep because the combination of the slip flow and dust cake effects. These results agree with our findings, as shown in Figs. 8, 9, and 10. As the filtration progresses, the formed compact cake predominate the filtration process as the fibers. The experimental shows that the surface filter medium is suitable to recover high dust concentration from the dust-laden gas in the on-line operational system.

4. Conclusions

During the depth filtration process, the deposited particles inside the filter medium cannot be readily removed during pulse cleaning. The depth filtration has high dust holding capacity and results in the clogging of the media. It is difficult for the clogged particles to be retrieved from the filter media during pulse cleaning. The depth filter medium is suitable to collect the low dust concentration in a long time operation system. During the surface filtration process, the slip flow results in the particles being trapped only on the superficial fibers, and not within. The surface fine fibers have the similar function with the formed dust cakes. The dust cake formation and pulse cleaning for surface filter medium is different from the depth filter medium. The surface filter medium is suitable to collect fine particles from the dust-laden gas.

As the filtration progresses, the actual dust cake filtration dominant, regardless of the depth filtration or surface filtration dominate at first. As the surface filtration progresses, the fine fibers of polytetrafluoroethene are not seen from the SEM with a long-term used media, but the particles are not trapped within the media, since the fine fibers may have been born off or formed the total dust cake with dust on the surface of filter cartridges which have been used for a long period of time. This phenomenon solves the perplexity of many industries that the efficiency of surface filter medium decreases if the polytetrafluoroethene fibers with ages are born off during pulse cleaning. This gives guidance to many industries for selecting the filter media. The surface filter medium is suitable to recover high concentration particles from the dust-laden gas in an on-line sustainable system.

The variety situations of particles pervading through filter media implemented in this study can be used to assess the cake formation and detachment. This study gives the effects of depth and surface filtration on the cleaning, and the surface filtration can help the cleaning of the fabric filter.

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