INFLUENCE OF FIBER DIAMETER ON FILTRATION PERFORMANCE OF POLYESTER FIBERS

by

Xin ZHANG*, Yue-Sheng FAN, Guo-Ji TIAN, Huan WANG, Hong-Li ZHANG, and Wei XIE

Key Laboratory of Environmental Engineering, School of Environment and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, China

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The filtration performance of four kinds of coarse polyester filters commonly used in the market was studied experimentally. The results showed that these filter materials had better filtration efficiency for particles larger than 5 μm. There was a significant difference among the same grade filters on filtration efficiency and resistance. The maximum counting efficiency of all four Samples can be achieved when the filtration velocity was 1.1 m/s. Fiber diameter was one of the main influencing factors that affect the efficiency and resistance of polyester filters. The comprehensive effect was relatively good when the Sample fiber diameter was small.

Key words: *polyester filter, particle size, counting filtration efficiency, fiber diameter, evaluation*

Introduction

In recent years, the deterioration of air quality has made air filters an essential product for life. The coarse filters have been widely used in the primary filtration of air conditioning systems and fresh air systems. The needs of people for filter materials are much more urgent than before. People want to understand the accurate filtration efficiency of the filter materials on different particle sizes more intuitively. Therefore, it is very necessary to study the counting performance of air filter materials.

At present, the manufacturing technique and equipment level of filter products are backward or imperfect. The performance of the filter materials is unstable, and the reliable filtration efficiency cannot be ensured. In addition, there is no uniform standard for filter materials testing. This is the leading cause of the difference in the performance of the same filter materials.

Numerous researchers have focused on the research of air filter filtration efficiency [1-3], new applications [4] and new materials [5-8]. Some achievements have been made, but the research on counting efficiency, efficiency range, and the construction differences of the filter materials at the same grade are still insufficient.

To overcome the above problems, four kinds of filter materials were studied experimentally from the aspects of counting filtration efficiency, resistance, and the construction differences of the same grade filter materials in this paper.

* Corresponding author, e-mail: 2601084634@qq.com

Methods

Four kinds of C3 and C4 grades filter materials were selected according to China's national standard (GB/T 14295-2008), labeled as Sample 1, Sample 2, Sample 3, and Sample 4, respectively. The GRIMM1.109 Portable Aerosol Spectrometer was used to measure the counting concentration of particles before and after the filter. Upper limit of counting concentration is 2000000P/L, and the particles ranging from 0.25 μm to 32 μm in diameter can be separated into 31 channels. HD2114P.0 Portable Micromanometer was used to measure filter resistance. The measuring accuracy is ±(2% reading + 0.1 m/s), and the pressure range is ±0.4% F.S. HD37AB1347 Indoor Air Quality Monitor was used to measure the velocity in the pipeline. The measuring accuracy range is ±3%. The experimental system of filter performance was established as shown in fig. 1. The experimental set-up was built according to China's national standard (GB/T 14295-2008). The distribution of measuring points was compiled according to China's national standard (GB50019-2015).

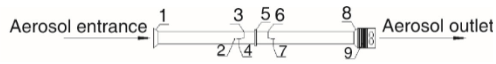
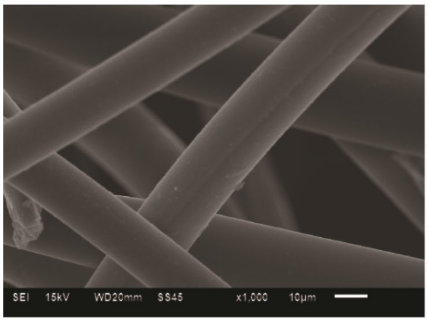


Figure 1. Experimental system; *1 – current collector, 2 – wind speed hole (side), 3 – upstream static pressure probe, 4 – upstream sampling heat, 5 – measured filter, 6 – downstream hydrostatic pressure probe, 7 – downstream sampling head, 8 – expanding tube, 9 – soft connection*

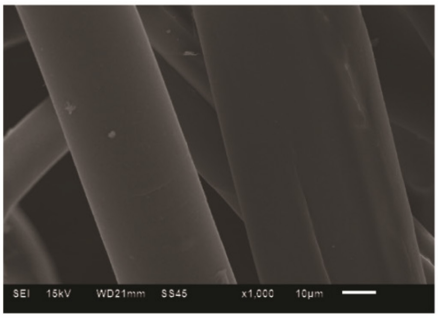
Results and analysis

Electron microscopy results

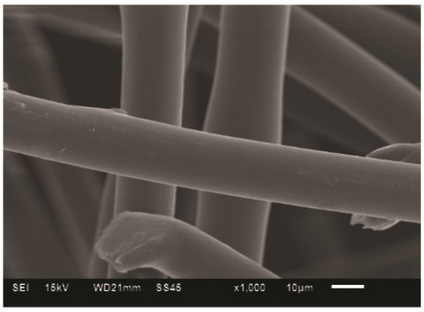
Figure 2 showed the electron microscope scan of the four filter materials under a magnification of 1000 times. The fiber thicknesses of the four filter materials shown in fig. 2



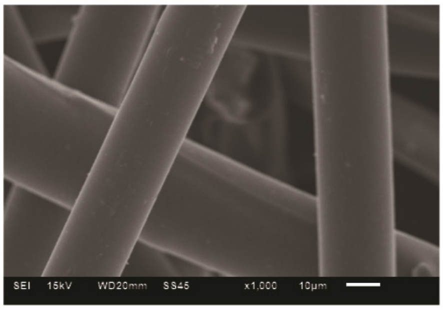
1000 time magnification of Sample 1



1000 time magnification of Sample 2



1000 time magnification of Sample 3



1000 time magnification of Sample 4

Figure 2. Four kinds of filter materials 1000 times electron microscope scanned

were quite different. Comparison between the two Samples of C3 grade filter materials showed that the fibers of Sample 2 were relatively thicker than those of Sample 1. Comparison between the two Samples of C4 grade filter materials revealed that the fibers of Sample 4 were relatively thicker than those of Sample 3. Among the four Samples of filter materials, the Sample fiber thickness distribution was: Sample 2 > Sample 4 > Sample 1 > Sample 3.

According to the electrical scan of fig. 2, the average diameter of filter materials was calculated, as shown in tab. 1.

Table 1. The main parameters of the experimental Samples

Grade	Number	Material	Specification (thickness：mm)	Fiber diameter [μm]
C3	Sample 1	Polyester	25·25·20	19
	Sample 2	Polyester	25·25·3	33
C4	Sample 3	Polyester	25·25·4	17
	Sample 4	Polyester	25·25·4	21

The impact of filtration velocity on the filtration effect

The outdoor atmospheric dust was directly used as the dust source [9]. The filtration velocity was changed from 0.8~1.2 m/s according to China's national standard (GB/T 14295-93, GB12218-1989). Figure 3 showed the counting filtration efficiency *vs.* filtration velocity, it is obvious that the counting efficiency is better for larger particles. The counting efficiency of the Sample 3 was the highest. Therefore, coarse filters were mainly used to filter particles larger than 5 μm.

It could be seen that the test results of the four filter materials had a similar trend. The counting efficiency increased with the filtration velocity, but when the filtration velocity reached a threshold of 1.1 m/s, an opposite trend was observed. This was because the interception effect increased when the dust-laden air flow passed through the fiber gap, and the diffusing effect and the inertial effect were both decreased. Under the condition that the filtration velocity was constant, the diffusing effect of the particles did not change, the particles captured by the filters due to Brownian motion were reduced, so that particles trapped by diffusion were reduced [10]. The fluctuation of the efficiency value of the Samples in the range of the filtration velocity might be related to the composition type of the local environment aerosol and the dust concentration [11].

The effect of different grades of filter materials on the filtration effect

Figure 4 showed that the counting filtration efficiencies of four Samples were compared when the filtration velocity was 1.1 m/s. For the particle sizes larger than 5 μm, the counting filtration efficiency was presented as Sample 3 > Sample 1 > Sample 4 > Sample 2 in order. The higher the grade was, the better the counting filtration was. Among the four Samples of filter materials, the counting filtration efficiency of Sample 3 of C4 grade was 17.5% higher than that of Sample 2 of C3 grade. In the C3 grade filter materials, the counting filtration efficiency of the Sample 1 was 5.65% higher than that of the Sample 2. In the C4 grade filter materials, the counting filtration efficiency of the Sample 3 was 7.01% higher than that of the Sample 4. Therefore, there was a significant difference between the same grade filters on filtration efficiency.

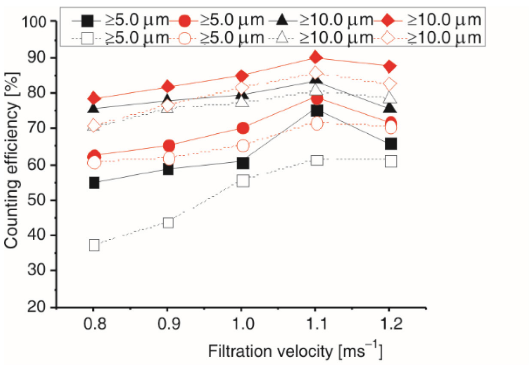


Figure 3. Filtration efficiency *vs.* filtration velocity Black: C3. Gray: C4, Solid line (−): Sample 1, Sample 3. Dotted line (- - -): Sample 2, Sample 4

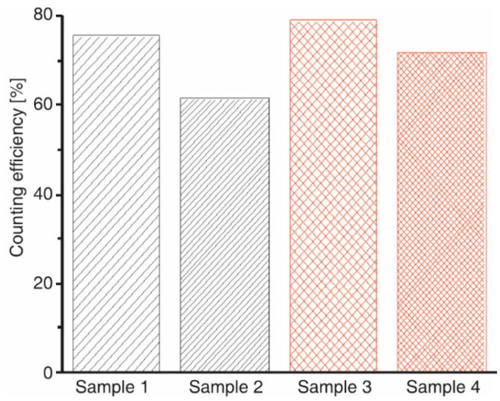


Figure 4. Filtration efficiency *vs.* different grades of filter materials

The effect of fiber diameter on the filtration efficiency

In order to analyze the effect of fiber diameter on the counting filtration efficiency, the counting filtration efficiencies of four Samples with different fiber diameters were compared at a filtration velocity of 1.1 m/s as shown in fig. 5.

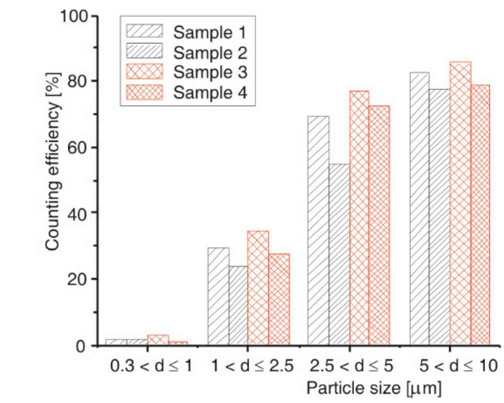


Figure 5. Classified filtration efficiency changed with the filtration velocity of 1.1 m/s

Figure 5 clearly showed that the fiber diameter of the Sample decreased, the counting filtration efficiency increased. The fiber diameter of Sample 3 was the smallest, and the counting filtration efficiency of the particles of each particle size was the highest. The fiber diameter of Sample 2 was the largest, and the counting filtration efficiency of the particles of each particle size was the lowest. For the particle sizes below 1.0 μm, the counting filtration efficiency of the filter materials was low and negligible. For particles with a particle size of 1.0~2.5 μm, the counting filtration efficiency was still very low, less than 35%. This was because for coarse filters, they were mainly used to filter particles larger than 5 μm. The larger the fiber diameter of the filter material was, the worse the filtration effect was on fine particles. So, there was not obvious for the filtration effect on small particle sizes.

For particles with a particle size of 2.5~5.0 μm, the counting filtration efficiency increased dramatically. The counting filtration efficiency of Sample 1, Sample 2, Sample 3, and Sample 4 was 69.48%, 55.07%, 77.08%, and 72.35%, respectively. Sample 1 with smaller fiber diameter in C3 grade had 14.41% higher counting efficiency than Sample 2. Sample 3 with smaller fiber diameter in C4 grade had 4.73% higher counting efficiency than Sample 4. Compared with the different grades of filter materials, the fiber diameter of Sample 3 was the smallest, the fiber diameter of Sample 2 was the largest, and the counting filtration efficiency of Sample 3 was 22.01% higher than that of Sample 2.

For particles with a particle size of 5.0~10.0 μm, the counting filtration efficiency of Sample 1, Sample 2, Sample 3, and Sample 4 was 82.39%, 77.65%, 85.60%, and 78.86%, respectively. Sample 1 with smaller fiber diameter in C3 grade had 4.74% higher counting filtration efficiency than Sample 2. Sample 3 with smaller fiber diameter in C4 grade had 6.74% higher counting filtration efficiency than Sample 4. Compared with the different grades of filter materials, the counting filtration efficiency of Sample 3 was 7.95% higher than that of Sample 2. With the continuous increase of the particle sizes, the difference in the counting filtration efficiency of all four Samples was increasing. The reason was that the interception and inertia effects became enhanced for the large particles while the fiber diameter was smaller.

Influence of fiber diameter on initial resistance

It could be seen from fig. 6 that the initial resistance and velocity of the filter materials showed an increasing trend, which was consistent with the theoretical situation. In the range of filtration velocity, the resistance range of Sample 1 was 33.5-69 Pa, the resistance range of Sample 2 was 19.5-39.5 Pa, the resistance range of Sample 3 was 23-52 Pa, and the resistance range of Sample 4 was 25-44.5 Pa. Sample 1 had a relatively large resistance range. When the filtration velocity reached 1.1 m/s, the resistance of Sample 1 was 57.5 Pa, the resistance of Sample 2 was 35.5 Pa, the difference between Sample 1, and Sample 2 in C3 grade filter materials was 22 Pa. The resistance of Sample 3 was 48.5 Pa, the resistance of Sample 4 was 41 Pa, the difference between Sample 3, and Sample 4 in the C4 grade filter materials was 7.5 Pa. Compared with the different grades of filter materials, the resistance was presented as Sample 1 > Sample 3 > Sample 4 > Sample 2 in order. Sample 2 had the least resistance, because the fiber diameter of Sample 2 was the largest. The smaller the fiber diameter was, the greater the resistance was. Conversely, the larger the fiber diameter was, the smaller the resistance was. In theory, the resistance value of Sample 3 should be the largest, but the result showed that the value of Sample 1 was the largest. This might be related to the thickness of the filter material itself. Wang Huaying [12] gave the relationship between resistance and filter thickness as ΔP~H through experiments. The thicker the filter material was, the greater the resistance of the filter material was, which verified the correctness of the conclusion of this paper.

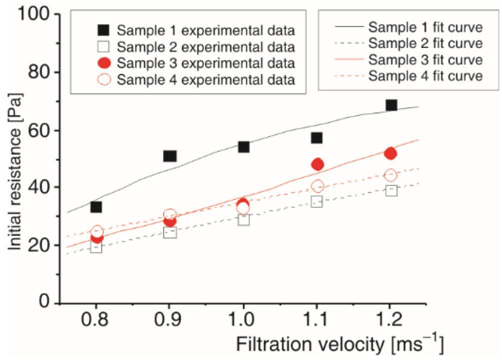


Figure 6. Initial resistance of four kinds of filter materials changed with the filtration velocity

According to fig. 6, the experimental data of initial resistance characteristic were linearly fitted. The results showed that all of the four filter materials had a good fitting quality as shown in tab. 2.

Table 2. The resistance fitting curve of the experimental Samples

Number	Filtration resistance (*Y*) – Filtration velocity (*x*) Fitting function	R^2
Sample 1	$y = -92.86x^2 + 262.71x - 114.8$	0.916
Sample 2	$y = -10.71x^2 + 71.93x - 31.2$	0.998
Sample 3	$y = 25.00x^2 + 27.50x - 15.60$	0.966
Sample 4	$y = 2.84x^2 + 49.00x - 14.00$	0.982

Conclusion

Through the testing and research on resistance, counting filtration efficiency of four grades of C3 and C4 coarse polyester fiber filters, it was found that the filtration effect on particles larger than 5 μm was excellent. There were obvious differences in the filtration efficiency and resistance of the same grade filter materials, and the higher the grade was, the better the effect was. When the filtration velocity was 1.1 m/s, the counting filtration efficiency of the coarse filter materials was maximized. The filter fiber diameter was one of the key factors affecting the filtration performance. The smaller the fiber diameter was, the higher the filtration efficiency and the greater the filtration resistance was. Conversely, the larger the fiber diameter was, the lower the filtration efficiency and the smaller the filtration resistance was. When the filter materials were used in practical application, both of counting filtration efficiency and resistance should be considered, it was really useful for manufacturers and designers to select of coarse filter materials. The hierarchical filter structure might be considered for high filtration efficiency and low resistance [13,14].

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References

[1] Bortolassi, A. C. C., *et al.*, Characterization and Evaluate the Efficiency of Different Filter Media in Removing Nanoparticles, *Separation and Purification Technology*, *175* (2017), Mar., pp. 79-86
[2] Tang, M., *et al.*, Filtration Efficiency and Loading Characteristics of PM2.5 Through Commercial Electret Filter Media, *Separation and Purification Technology*, *195* (2018), June, pp. 101-109
[3] Serhat, N. A. G., *et al.*, Optimization of Centrifugally Spun Thermoplastic Polyurethane Nanofibers for Air Filtration Applications, *Science and Technology*, *52* (2018), 5, pp. 515-523
[4] Chen, T., *et al.*, Numerical Simulation of the Air Flow Field in the Foreign Fiber Separator, *Thermal Science*, *20* (2016), 3, pp. 953-956
[5] Li, Y., *et al.*, High Temperature Resistant Nanofiber by Bubbfil-Spinning, *Thermal Science*, *19* (2015), 4, pp. 1461-1462
[6] Seema, A., *et al.*, Functional Materials by Electrospinning of Polymers, *Progress in Polymer Science*, *38* (2013), 6, pp. 963-991
[7] Shen, J., *et al.*, Effect of Pore Size on Gas Resistance of Nanofiber Membrane by the Bubble Electrospinning, *Thermal Science*, *19* (2015), 4, pp. 1349-1351
[8] Dou, H., *et al.*, Wave-like Beads on Nanofibers by Blown Bubble Spinning, *Thermal Science*, *18* (2014), 5, pp. 1477-1479
[9] Parham, A., *et al.*, Estimates of HVAC Filtration Efficiency for Fine and Ultrafine Particles of Outdoor Origin, *Atmospheric Environment*, *98* (2014), Dec., pp. 337-346
[10] Rosner, D. E., *et al.*, Local Size Distributions of Particles Deposited by Inertial Impaction on a Cylindrical Target in Dust-Laden Streams, *Journal of Aerosol Science*, *26* (1995), 8, pp. 1257-1279
[11] Charvet, A., *et al.*, Experimental and Modelled Efficiencies during the Filtration of a Liquid Aerosol with a Fibrous Medium, *Chemical Engineering Science, 65* (2010), 5, pp. 1875-1886
[12] Wang, H. Y., A Study of Filtration Fabric's Purifying Performance to PM_{10} (in Chinese), M. Sc. thesis, Donghua University, Shanghai, China, 2003
[13] Liu, Y.Q., *et al.* Air Permeability of Nanofiber Membrane with Hierarchical Structure, *Thermal Science, 22* (2018), 4, pp.1637-1643
[14] Wang, F. Y., *et al.*, Improvement of air Permeability of Bubbfil Nanofiber Membrane, *Thermal Science, 22* (2018), 1A, pp. 17-21

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