NANOFIBERS IN FILTRATION

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With the modern definition, "nano" technically refer to physical quantities within the scale of a billionth of the reference unit [1] and nanofibers are the fibers with diameters in the nanometer range. Nanofibers can be generated from different polymers and hence have different physical properties and application potentials. Nanofibers are produced in the form of spider web like structures, with a very large surface area and a large number of pores with very small pore size.

Because of its relative ease of use and ability to fabricate nanofibers, electrospinning is one of the most commonly used methods for the production of nanofibers. In electrospinning, a high voltage power source, a nozzle and a collector are used [2]. The produced nanofiber media have a low basis weight, high permeability and small pore size that make them appropriate for use in a wide range of filtration applications, particularly for smaller particles [3]. Since the filtration and separation of sub-micron sized contaminants is a major concern of modern day technology, nanofibers and nanofiber layers on a filter media are the key elements for improving the filtration efficiency. The nanofiber layer collects dust, dirt and contaminants on the surface of the filter; and this layer increases the filtration efficiency of the conventional filters such as cellulose, cellulose/synthetic, spunbond, or meltblown filtration media.

Nanofibers offer unique properties such as high specific surface area (ranging from 1-100 m2/g depending on the diameter of the fibers and intrafiber porosity) and good interconnectivity of pores [4]. Nanofibers are fragile, are usually not used alone in filtration, and generally are produced onto conventional filter media (Figure 1) [3]. Nanofiber filter media have set new levels of filtration performance in various diverse applications within a wide range of environments.

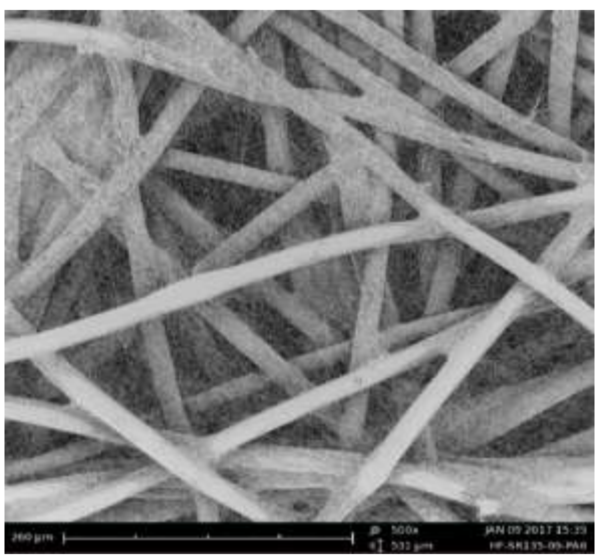


Figure 1. Nanofiber performance layer filter

There are four main types of relevant filtration mechanism using nanofiber filter media. These are surface straining, depth straining, depth filtration and cake filtration [1]. In practice, the filtration processes often involve a combination of two or more mechanisms. In surface filtering (Figure 2b.), the surface of filter media plays an active role and the surface pore openings of filter media are precisely controlled in relation to the particulate size to be filtered. The use of nanofibers and smaller pore sizes in surface filtering is aimed at capturing the particles at the surface of the medium. The surface pore openings of filter media could be precisely controlled in relation to the particulate size to be filtered. It is known that the filter efficiency is improved when the fiber diameter of the filter media decreases [5]. The efficiency curves have a ‘V’ shape, and the deepest point of the ‘V’ indicates the most penetrating particle size (MPPS). The MPPS decreases and the capture efficiency of the most penetrating particle size increases with decreasing fiber diameter [1, 5-7]. Finer nanofibers generally enable greater filtration efficiency, particularly for the most penetrating particle size.

Depth straining type of filter media (Figure 2a.) is relatively thick compare to surface filter media and the pores are variable in the flow path length. Depth filtration uses various physical mechanisms for removing a particle from a fluid even though the particle may be smaller than the pore diameter at any point in the pore structure.

In cake filtration (Figure 3), the filter medium begins the filtration process; successive layers of particles deposit on the top of preceding layers to form a cake (Figure 3b) [4].

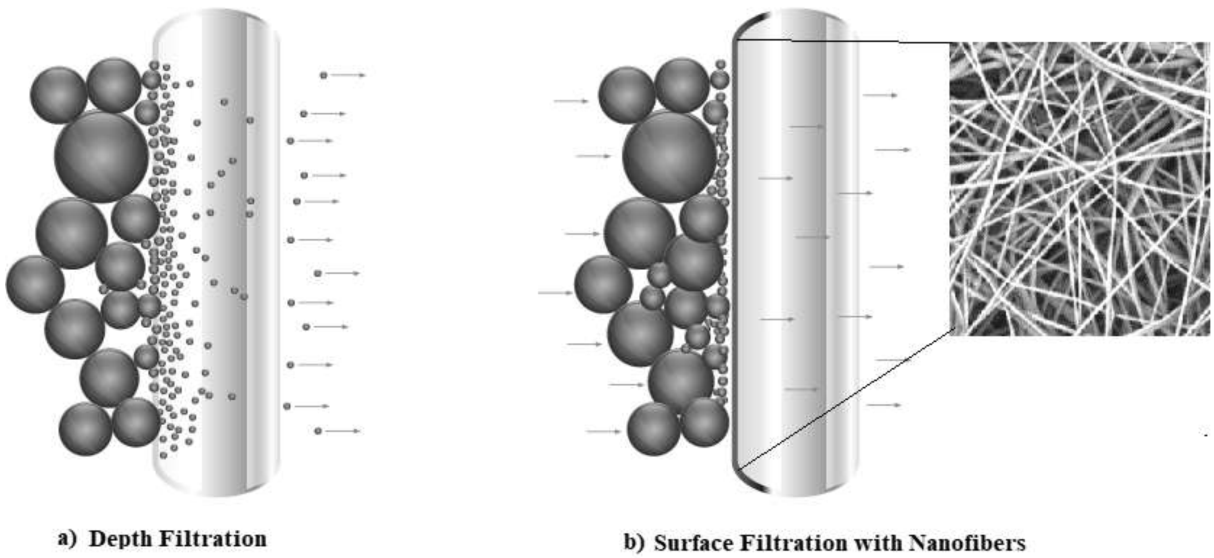
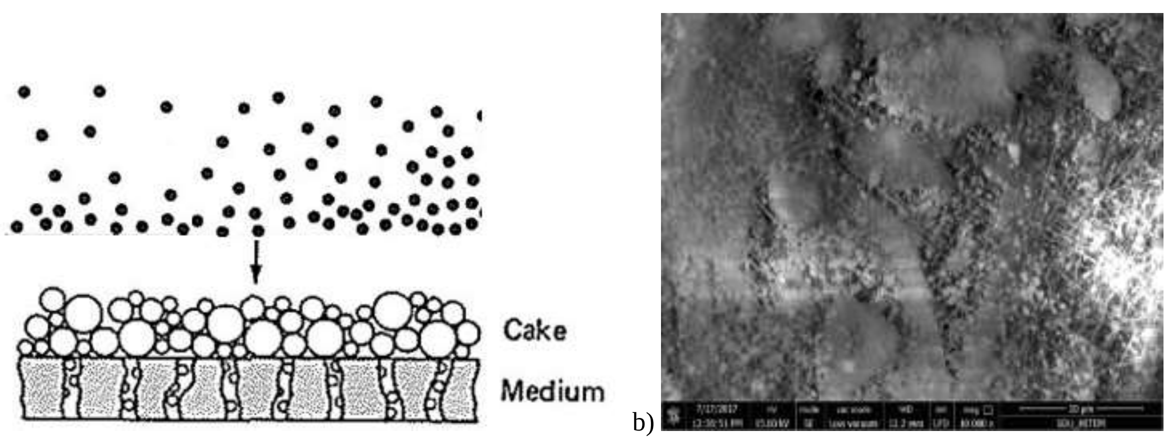


Figure 2. a) Depth filtration, b) Surface filtration with nanofibers

a) 

b)

Figure 3. a) Cake filtration, b) Deposition of the particles on the upper side of the nanofiber media

DUST COLLECTION SYSTEM AND AIR FILTRATION WITH NANOFIBERS

A dust collection system is an air quality improvement system that uses air filters in industrial, commercial buildings and as well as at our homes to improve breathable air quality and safety by removing particulate matter from the air and environment. In dust collectors a filter is cleaned generally by a reverse-pulse of compressed air (back pulse). With a nanofiber performance layer filter, the dust accumulates on the surface of the filtration media rather than within the media and could be cleaned off with a back pulse. Because of the deposition of the dust on the surface and easy clean ability with back pulse, a nanofiber fiter media can be used longer. In heavy-duty air, dust collector, and cleanable media, the nanofiber layer is applied upstream in order to use this benefit.

Most dust collection systems uses a fan to draw dust-laden air to a collector through the filtration media. The energy required to move the air through the filtration system is related with the necessary fan size and the energy that required for the operation of the system. Because of the high capture efficiency of a nanofiber layer, just a thin nanofiber layer is coated on the surface of conventional filter media. The nanofiber layer media captures dust on the surface reducing depth loading. Besides, lower pressure differentials could be obtained. Upstream nanofiber layer could be cleaned more completely and operates at a lower pressure differential across the filtration media which resulted in reduced energy demands for operation.

One of the most important problem with these structures is that they often designed for good cake release properties, however, they are often poorly adhered to the substrate and have a tendency to blow or peel off when reverse air cleaning is applied. However advanced Hifyber nanofiber technology overcome this drawback and produced nanofiber performance layers are very durable to back pulses and show long lasting efficiency.

COMPOSITE FILTERS INCLUDING NANOFIBER INTER LAYERS

In contrast to heavy-duty air, dust collector, and cleanable media, nanofiber layers could be also applied as an interlayer in applications where depth filtration is needed. In depth filtration, it is important for particulates to be captured and confined within the air filter media. Such multiple layered structures (Fig.4) can be designed by combining a high porosity, bulky layer on the upstream side for macro filtration with a high filtration nanofiber efficiency layer on the downstream side; in effect a pre-filter and final filter within the same medium. Upstream side act as a “capacity layer” which is followed by downstream “efficiency layer”. The downstream nanofiber layer coated substrate greatly improve the particle capture efficiency, trap the fine particles that penetrate the capacity layer. The capacity layer is intended to be a porous bulky substrate designed to trap large quantities of large particle dirt while increasing dust-holding. This layer also protect nanofiber efficiency layer being damaged and clogged up early with large dirt particles.

The usage of more open, bulkier capacity layer results in a greater efficiency at the same air permeability, but also with significantly improved dust-holding capacity.

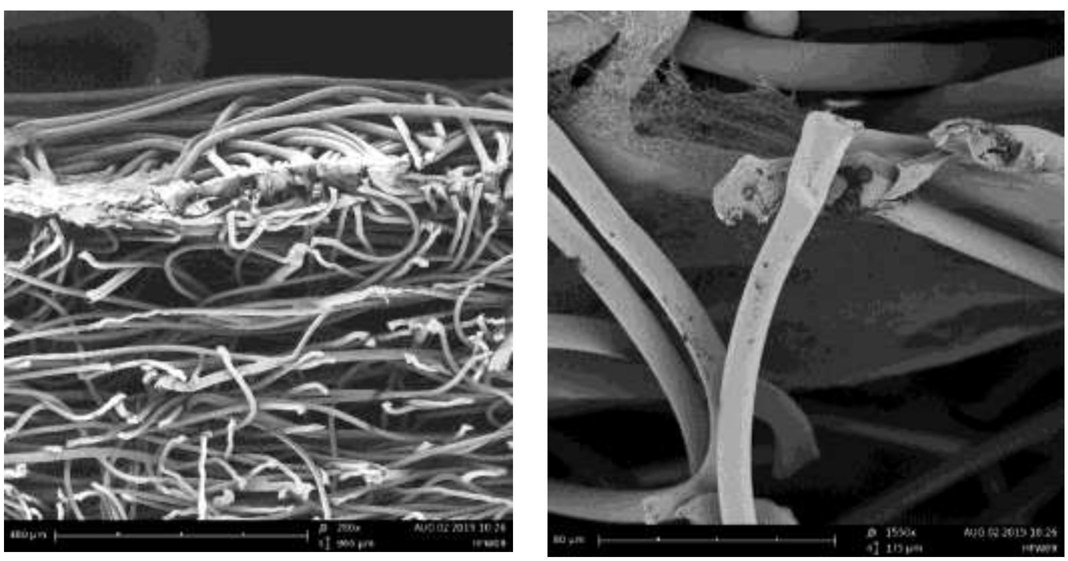


Figure 4. Cross-section of composite filter including nanofiber inter layer a) Magnification of 280x and b) 1550x

CONCLUSION

Nanotechnology has provided several novel products with superior properties for a wide range of applications and nanofiber is one of the major successes of nanotechnology [8]. BCC Research of “Global Markets and Technologies for Nanofibers” estimated that the global market for nanofiber products would grow from $927 million in 2018 to $4.3 billion by 2023 at a compound annual growth rate (CAGR) of 36.2% for the period of 2018-2023 [9]. Nanofiber-spun webs for nonwoven and filtration purposes are the part of the growth [3]. There are many applications of nanofibrous filters that are already commercialized in addition to the applications that are still under development [4]. Today, more people involved in the air filtration market are looking at nanofiber treated media in order to improve filtration efficiency.

REFERENCES

[1] Ramakrishna, S., Fujihara, K., Teo,W., Lim,T. and Ma, Z., (Eds.), 2005, An Introduction to Electrospinning and Nanofibers, World Scientific Publishing Co. Pte. Ltd., Singapore, 396p

[2] Teo WE, Ramakrishna S. A review on electrospinning design and nanofibre assemblies. Nanotechnology 2006 17(14):R89–106.

[3] I. M. Hutten, Handbook of nonwoven filter media. Oxford: Elsevier, 2016, ch.8

[4] R S. Barhate, S. Sundarrajan, D. Pliszka and S. Ramakrishna, “Fine chemical processing: The potential of nanofibres in filtration” Filtr Separat, 45(4) 32-35, 2008.

[5] Chase GG, Swaminathan S and Raghavan B. Functional nanofibers for filtration applications. In: Wei Q (ed) Functional nanofibers and their applications. Elsevier, 2012, pp. 121-152.S.

[6] Wang N, Yang Y, Al-Deyab SS, El-Newehy M, Yu J, Ding B. Ultra-light 3D nanofibre-nets binary structured nylon 6-polyacrylonitrile membranes for efficient filtration of fine particulate matter. *J Mater Chem A*. 2015;3(47):23946–54.

[7] Podgórski A, Bałazy A and Gradoń L. Application of nanofibers to improve the filtration efficiency of the most penetrating aerosol particles in fibrous filters *Chem Eng Sci.* 2006; 61:20: 6804-6815.

[8] https://www.marketwatch.com/press-release/nanofiber-technology-to-boost-pharmaceutical-filtration-market-technavio-2017-10-17, Accessed on 06 August 2019

[9] https://www.bccresearch.com/market-research/nanotechnology/global-markets-and-technologies-for-nanofibers.html#, Accessed on 06 August 2019