B―28　多層ナノファイバーメディア：高性能な空気濾過のための新しい設計アプローチ

Multi–layered nanofiber media: A novel design approach for high performance air filtration

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英　文　概　要

Air cleaning is a major concern in many industries and end–users becoming more aware of the health issues, effects and benefits of high quality filtration. Nanofibers are an exciting class of materials due to their extremely high specific surface area, inter–connected pore structure and high porosity for gas permeability. Such unique properties provide significant benefits in a wide range of air filtration applications. Elmarco's reference media design demonstrates how nanofibers can be utilized within a composite structure to achieve high mechanical filtration efficiency, high dust holding capacity and low pressure drop. The nanofiber layer which features excellent web and fiber uniformity shows no impact from discharge test and pleating process.

キーワード
エアフィルタ、ろ材　air filter; filter media

Airborne dust and chemicals continue to be serious problems, with harmful effects on human health and on industrial processes that rely on clean air. Poor indoor air quality has been linked to the exacerbation of asthma symptoms in children. In 2007, the U.S. Centers for Disease Control and Prevention reported that 1 in 13 school-aged children have asthma in the United States. Also, the European Commission estimates that approximately 370,000 people die prematurely due to the presence of fine dust annually. Consequently, there is an increasing customer demand for higher performing products, and filter media producers are enhancing their media designs and exploring new technologies. By owing high specific surface area, inter-connected pore structure and high porosity, nanofibers offer industry proven solution to improve the filtration performance and are the current trend in air filtration technology. It is well known that a thin nanofiber layer on the upstream side significantly improves the filtration efficiency at a lower pressure drop and demonstrates excellent surface–loading capacity. Yet its application in depth–loading filtration has not been fully explored. Elmarco partnered with industry-leading companies to develop a novel approach to design a composite reference media for depth filtration. Figure 1 shows the composite media design which consist from three layers. The upstream –capacity layer– comprising synthetic fibers with a relatively large pore structure has three main functions; i) pre-filtering of large particulates, ii) preventing nanofiber layer from clogging, and iii) providing high dust holding capacity. The mid –nanofiber layer– exhibits high specific surface area, interconnected pore structure, and small pore which enables to reach high filtration efficiencies at relatively low pressure drops. The downstream –stiffening layer–protects the nanofiber layer while improving the media rigidness for enhanced pleatability [1].

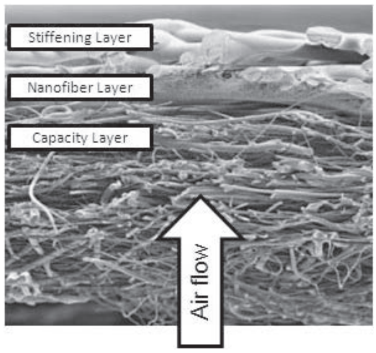

Figure 1. Cross-section SEM picture of the composite media

The composite reference media is prepared by coating polyester (PET) spun bond (stiffening layer) with polyacrylonitrile (PAN) nanofibers by using Elmarco's state–of–art 1.6 meter width industrial production line which is built on the needle-free Nanospider™ technology. Afterward, the nanofiber coated layer

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is laminated with polypropylene (PP) melt blown and pleated by using common technologies. Pleat density and geometry can be further optimized to provide the desired efficiency at the least possible pressure drop. Also, a wide range of performance targets are achievable by optimizing the basis weight, fiber diameter, pore size and porosity of each layer. The prepared media is used to build a high efficiency mini-pleat V-bank filter (Figure 2) for residential, commercial and industrial HVAC applications.

Figure 2. High efficiency mini–pleat V–Bank filter

Filters are tested according to standard ASHRAE 52.2 at a third party laboratory and results are given in Table 1. Performance benchmarking with industry–leading products clearly shows that the reference media design provides a significant improvement in the initial pressure drop and dusting holding capacity up to 30% and 50%, respectively.

Table 1. Reference filter test results (ASHRAE 52.2)

Nominal dimensions (H x W x D)	610 x 610 x 305 (mm)
Media area	16 m^2
Nominal face velocity	2.5 m/s
Initial pressure drop	82 Pa
Efficiency Rating per ASHRAE 52.2: 2007	MERV15 (F9) @ 0,944 m^3/s
Efficiency Rating per ASHRAE 52.2: 2007 Appendix J	MERV15A (F9) @ 1968 cfm
Dust holding capacity	300 g @ 375 Pa
Min. Composite Efficiency (%) after KCL conditioning	E1 - A (0.3 - 1.0 μm): 89 E2 - A (1.0 - 3.0 μm): 98 E3 - A (3.0 - 10 μm): 100

The improvement can be mainly attributed to the gradient media structure where the pore size and fiber diameter gradually decreases from upstream to downstream side. In particular, for fibers in nano–scale, the effect of slip flow at fiber surface has to be taken into account, where the air velocity at fiber surface is assumed to be non–zero. Gas flow in fibrous filter can be classified in four regimes according to the Knudsen number (Kn) as follows: 1–continuous regime (Kn<0.001), 2–slip flow regime (0.001<Kn<0.25), 3–transition regime (0.25<Kn<10), and 4–free molecular regime (Kn>10). Knudsen number is given with the following formula, $Kn=2\lambda/Df$, where λ is the air mean free path (66 nm) and Df is the fiber diameter. From the scanning electron microscope (SEM) picture of PAN nanofibers given in Figure 3, the mean fiber diameter is measured as 175 nm (CV ± 25 nm). In this case, the corresponding Knudsen number is 0.75 in which air flow over fibers belongs to the early transition regime and the no–slip boundary condition at the fiber surface is no longer valid. Due to the slip at fiber surface, drag force on a fiber is smaller than that in the case of non–slip flow which translates into a lower pressure drop. On the other hand, the slip flow provides a larger portion of air flowing near the fiber surface which translates into more particles traveling near the fiber, resulting in higher diffusion, interception and inertial impaction efficiencies.

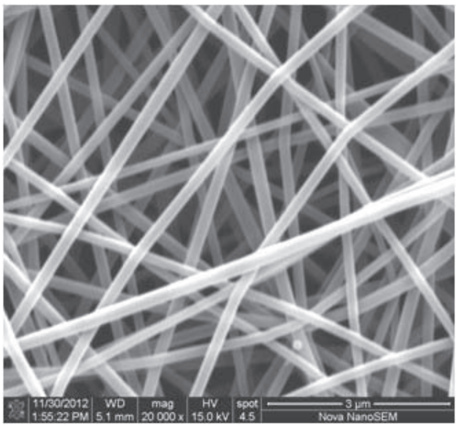

Figure 3. SEM picture of PAN nanofibers

Filters are also tested after discharging with potassium–chloride (KCL) according to Appendix J given in the same standard. As seen from Figure 4, there is no drop in filtration efficiency after the discharge test which confirms that nanofibers are durable against KCL and the filtration mechanism is completely based on mechanical filtration at pressure drop levels of electret media and it does not degrade under varying environmental conditions as charged meltblowns are prone to do.

It is a common view that the nanofiber layer cannot withstand the external forces associated with the pleating process and can damage. In order to investigate the effect of pleating process on nanofiber layer integrity, samples from pleat tip are examined by SEM. As shown in Figure 5, no damage in nanofiber layer was observed after the pleating process. Further SEM investigation proved that the applied adhesion plays a key role and significantly improves the mechanical durability of the nanofiber layer against the pleating process while its effect on initial pressure drop is negligible. The application of adhesion does also increase the overall stiffness of the media which results in enhanced pleatability that previously could not be achieved in synthetic media. Due to its high stiffness and easy pleatability, the reference media is self-supporting and requires no wire backing.

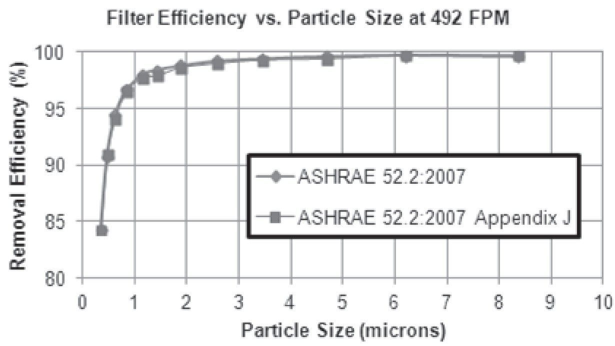

Figure 4. Effect of discharge on filtration efficiency

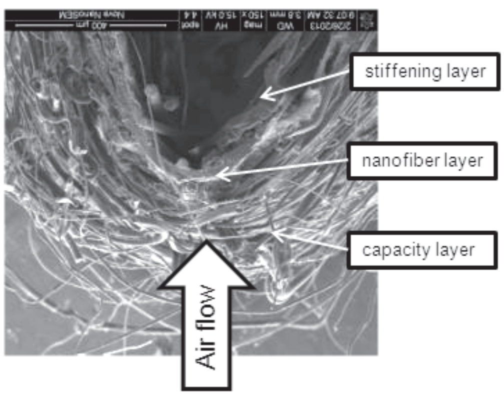

Figure 5. SEM picture of a pleat-tip of composite media

The wet laid microglass media used in HVAC (heating, ventilation, and air conditioning) filters can exhibit brittle characteristics, which generally make the filter media sensitive to handle and difficult to pleat and produce undesirable yield losses. Further, there is a potential for the glass fibers to break off and enter passing air creating a serious health problem. Therefore, a trend is developing to shifting to fully synthetic media which provides a lower pressure drop across the entire filter. The MERV15 / F9 reference filter demonstrates superior pressure drop and dust holding and outlines a path for media producers and filter manufacturers to further improve by numerous design parameters to optimize their final filter. The fully synthetic reference filter was made with commercially available materials using commonly used manufacturing processes and can be readily produced at standard industry pricing. This novel media design approach allows producer to design each layer independently in order to reach different filtration characteristics to further improve indoor air quality, which is especially important in public buildings, such as hospitals and schools, and crucial to protect people and help alleviate sick building syndrome (SBS). From commercial point of view, these performance advantages lower the kWh usage profile of filters in application leading to lower system operating costs. As multi–layer composite media concept meets all industry requirements it can be used in a wide range of filter types and grades.

<Reference>

[1] Product datasheet and application note at www.elmarco.com