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Development and Evaluation of Multilayer Air Filter Media

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Abstract−Three types of multilayer air filter media were developed and evaluated. Two other existing filters were also used for comparison of filter performance. The pressure drop, the collection efficiency, and the dust-holding capacity of the tested filters were measured, and the internal structure of the filter media was analyzed by using a scanning electron microscope. The multilayer filters tested in this study are composed of pre-surface layer, surface layer, and substrate layer. Among those layers, the surface layer is mainly responsible for particle collection. As a test result, it was found that the thickness of a surface layer has the greatest effect on filtration performance of a multilayer air filter. Additionally, filtration velocity and electrostatic forces should be considered together as important parameters for multilayer air filter design.

Key words: Multilayer Air Filter, Pressure Drop, Collection Efficiency, Surface Layer, Filtration Velocity

INTRODUCTION

Dust particles in the intake air of turbomachinery such as gas turbines or high capacity compressors can do serious damage to the machines. Generally, turbomachines need high flow rate of process air, so the amount of dust particles in the air is also very large. Furthermore, the flow velocity inside the turbomachines is extremely high, and the air is heated up to above 1,500 °C and highly compressed. Therefore, the particulate pollutants contained in the process air have a mechanical force strong enough to do major damage to turbine blades. According to Schroth [1993], the erosion, abrasion, and corrosion on the surface of the blades can be caused by submicron particles. Those mechanical problems lead to a performance decline of the turbomachines.

In order to remove the dust particles from the intake air of turbomachinery, a high efficiency air filtration system is needed. Air filters used for this purpose are of several different types including cartridge, pocket, and cassette type filters. The application of those filters is determined by field situations, the particle concentration, and necessity of a filter cleaning process. As a guideline for filter selection, the collection efficiency and pressure drop characteristics are equally important factors. As mentioned above, the collection efficiency of a turbine intake air filter can directly affect the performance of the turbine. Dust caking as well as the mechanical damages on turbine blades due to dust particles can be effectively reduced by a high efficiency air filtration system. The high pressure drop across an intake air filter can cause a significant decline of turbine performance. For example, as the pressure drop of a gas turbine intake air filtration system is increased by 500 Pa, 1% decrease of the power output and 0.5% reduction of the thermal efficiency are brought out [Schroth, 1993]. The fact that the collection efficiency and the pressure drop of a filter have opposite positions in the view of the filter performance is well known. That is, high efficiency air filters usually have low air permeability. On the other hand, the collection efficiency of a filter having a low pressure drop is very low. Various studies have been conducted to overcome the tradeoff characteristics of air filters. Electret filters are the representative results of those studies [Baumgartner and Loeffler, 1986; Lathrache et al., 1986; Kanaoka et al., 1987]. Improving the filter material and the innovative design of filter structure have also been tried as an alternative method to achieve the low pressure drop and the high collection simultaneously [Abrams et al., 1994; Bacino, 1995; Caldwell, 1998; Park et al., 2000].

This study has been performed to develop a high efficiency turbine intake air filter. The objective of the present study is to analyze the effect of the design parameters for multilayer air filters on filtration performance. The methodology used is to analyze the inner structure of several multilayer air filters having different layer features, to evaluate the filtration efficiency of the filters, and finally to find out the effects of design parameters on the performance of multilayer air filters.

TESTED FILTER MEDIA

Three types of air filter media composed of synthetic fibers were newly developed through this study. The developed filter media are aimed at application for gas turbine intake air filters.

The newly developed filter media have multilayer structure. One has two layers, and the others three layers. Two-layer filter media are composed of meltblown polypropylene (PP) fiber surface layer and chemical bonded polyester (PET) fiber web as a substrate layer. Those two layers are thermally bonded using the polyethylene (PE) powder. The other two media consist of three layers: the spunbond PET pre-surface layer, the meltblown PP surface layer, and the chemical-bonded PET substrate web. Each layer is bonded by the ultrasonic bonding method. Fig. 1 shows the SEM images of the upstream surface of tested filters including two existing ones. From Fig. 1, it can be seen that K01, RF01, and RF02 have no pre-surface layer, and the fiber size range of the filters is nearly the same.

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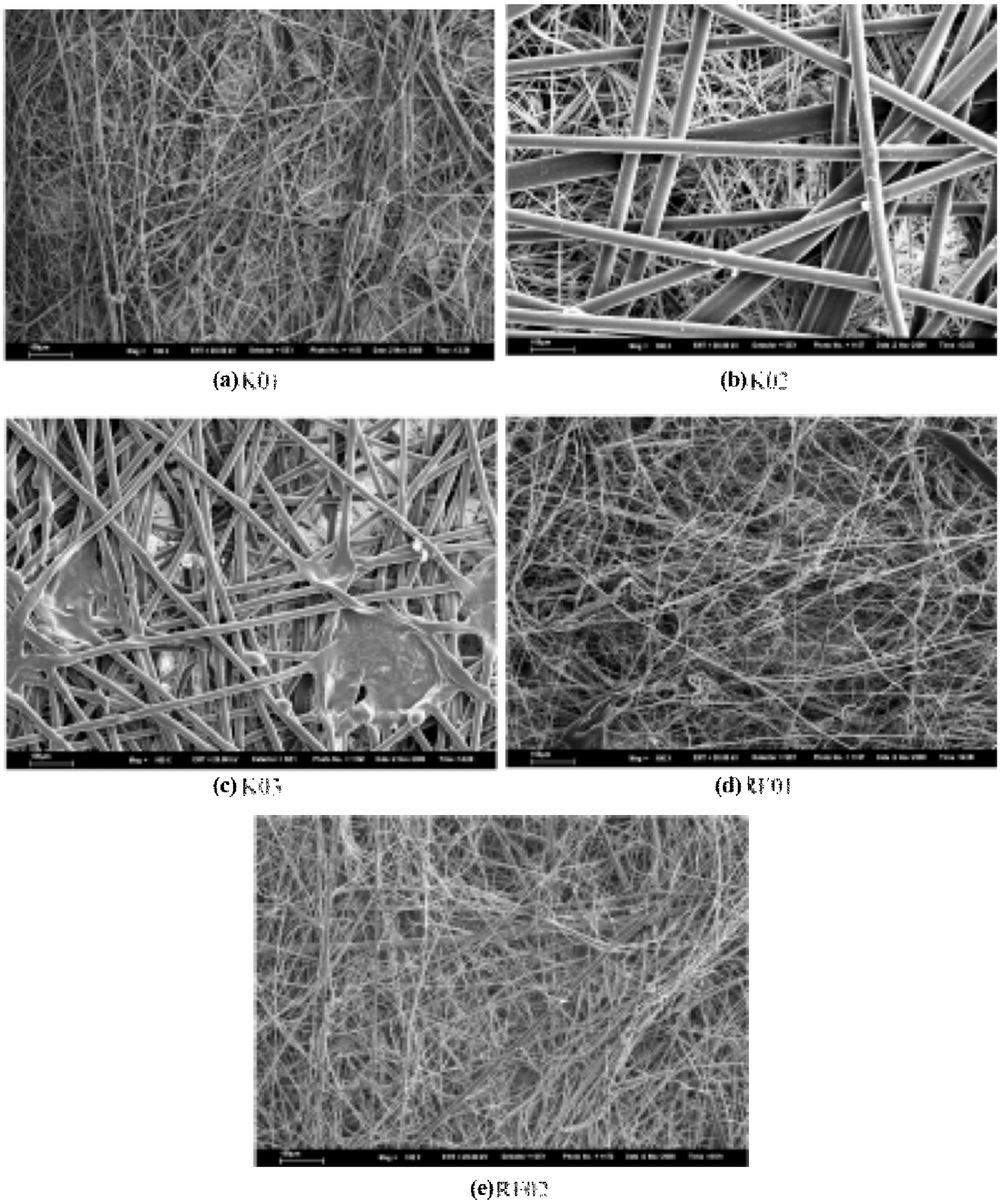

Fig. 1. SEM images of upstream surface of tested filters; (a), (b), and (c): newly developed filter media, (d) and (e): existing filter media.

The same PP fiber web was used for K01, K02, and K03 filter media as a surface layer, but the thickness of the layer for each filter is slightly different. For the case of K02 and K03, the pre-surface layer was employed. The meltblown PP fibers are so weak in their strength that they can be easily damaged from an external impact or mechanical forces. Therefore, a protection layer is needed. In Fig. 1(b) and 1(c), the large and straight fibers are of the pre-surface layer. The information on the filter media is summarized in Table 1.

EXPERIMENTAL PROCEDURES

Basically, the pressure drop across the filter media was measured by a micromanometer for the various face velocities, and the collection efficiency was also measured by using particle counters. Based on the SEM photos of the tested filter media, the structure inside the filters was analyzed.

The schematic diagram of the experimental setup is depicted in Fig. 2. As a test dust, NaCl particles were used. The NaCl particles were generated by an aerosol atomizer using 0.1 N NaCl solution, and perfectly dried by passing through a diffusion dryer which is filled with silica gel materials. The geometric mean diameter (GMD) of the NaCl particles is about 0.8 μm, and the geometric standard deviation (GSD) is about 2.0. The particles entering the electrostatic classifier (Model 3080, TSI Inc.) are classified into a monodisperse aerosol having a particle size ranging 0.005-1 μm. The size of the monodisperse particles can be selected by controlling the applied voltage into the classifier.

Table 1. Fiber materials and structural features of the tested filter media

Filter media	Layers	Materials	Manufacturing process	Bonding method	Remark
K01	Surface layer	PP	Meltblown	Thermal bonding	
	Substrate layer	PET	Chemical bonded	using PE powder	
K02	Pre-surface layer	PET	Spunbond	Ultrasonic bonding	Newly developed
	Surface layer	PP	Meltblown		
	Substrate layer	PET	Chemical bonded		
K03	Pre-surface layer	PET	Spunbond	Ultrasonic bonding	
	Surface layer	PP	Meltblown		
	Substrate layer	PET	Chemical bonded		
RF01	Surface layer	PP	Meltblown	Ultrasonic bonding	Existing
	Substrate layer	PET	Chemical bonded		
RF02	Single layer	Glass fiber	Wet laid		

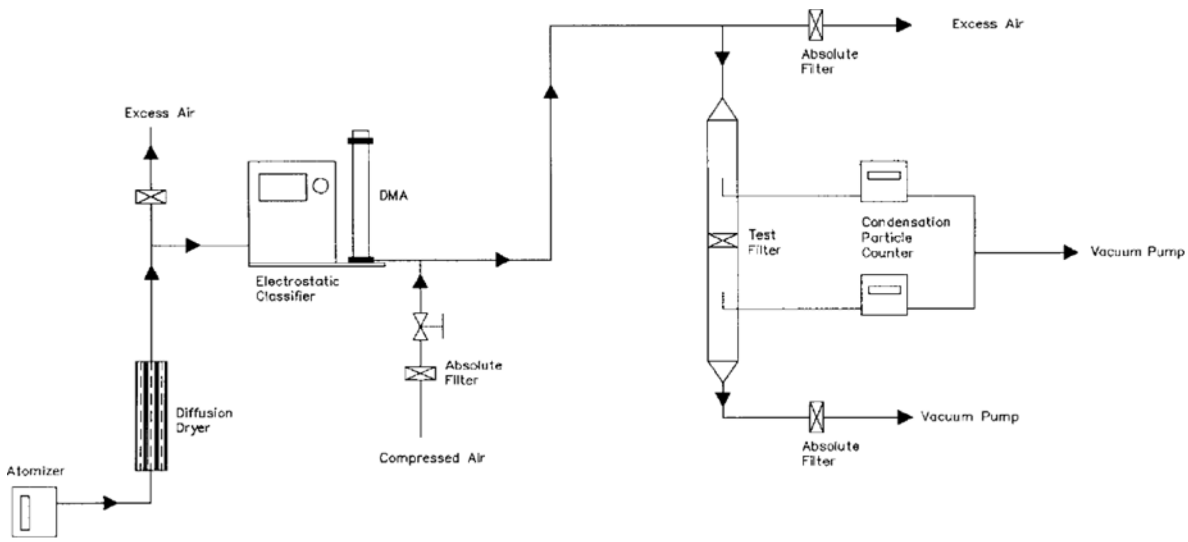

Fig. 2. Schematic diagram of the experimental setup.

The filter test column is a stainless steel cylindrical pipe, and its size is 42 mm in inner diameter and 800 mm in length. The shape of tested filter samples is circular. The diameter of the filter samples is 50 mm, but actually only 42 mm in diameter contributes to the filtration area. The filter samples are installed in the middle of the test column and perfectly sealed.

As for the experimental conditions, the temperature was maintained at 18-23 °C, the relative humidity was 40-50%, and the experiment was conducted under atmospheric pressure. The particle concentrations are calculated by counting the particle numbers during a predetermined sampling time. Two condensation particle counters (Model 3010, TSI Inc.) count the upstream and downstream particle numbers, respectively. Thus, the fractional collection efficiency of a tested filter medium is calculated by the following equation.

$$\eta(\%)=\frac{N_{UP}-N_{DOWN}}{N_{UP}}\times 100 \qquad (1)$$

where

η : fractional collection efficiency
N_{UP} : upstream particle counts
N_{DOWN} : downstream particle counts.

RESULTS AND DISCUSSIONS

The characteristics of pressure drop of the tested filters at various filtration velocities are shown in Fig. 3. The K02 filter has the lowest pressure drop, and the RF01 shows the highest flow resistance characteristics. It is well-known that the pressure drop of a

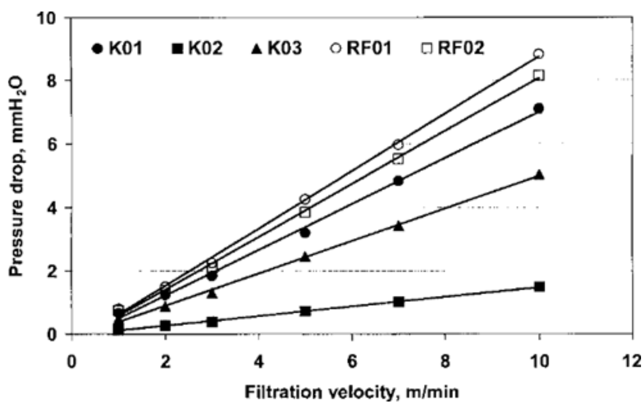

Fig. 3. Comparison of pressure drop characteristics of the tested filter media.

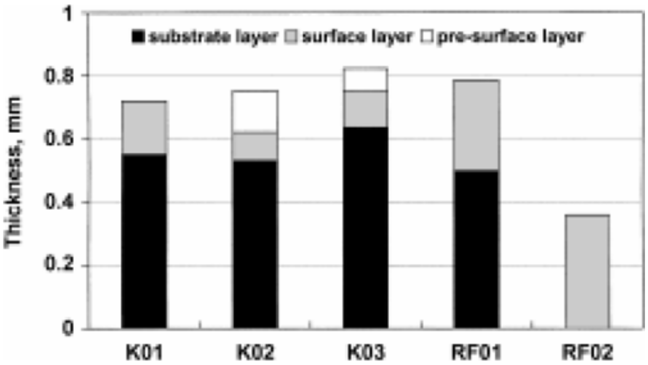

Fig. 4. Thickness data of the tested filter media.

filter is linearly proportional to its thickness. For a multilayer filter, the surface layer mainly contributes to the pressure drop of the filter. Therefore, information on the structure of the tested filters is needed. In this work the thickness of each layer for the filters was measured by using a scanning electron microscope (SEM).

The thickness data is graphed in Fig. 4. As can be seen, the K02 filter has the thinnest surface layer. The RF01 has the thickest surface layer, as expected from the pressure drop data. For the case of K02, especially, the thickness of the surface layer is very thin. Furthermore, it is not uniformly distributed. That is, the thickness is not equal over the surface web. This non-uniformity of the surface layer causes the low pressure drop, and it may also bring out the poor collection efficiency.

The pressure drop of the RF02 is lower than that of the RF01, even though the thickness of the RF02 is greater. This is likely due to the difference of fiber materials used and the porosity of the surface layer. The K01, K02, K03 and RF01 have the same fiber material for the surface layer, on the other hand, the RF02 is composed of a single layer of glass fibers.

Another parameter to evaluate the filter performance is the collection efficiency. The collection efficiency of the tested filter was measured for submicron sodium chloride particles. The results are shown in Fig. 5. The K01 is the most excellent among the five filters, and the K02 having the lowest pressure drop shows the worst collection efficiency. The efficiency of the RF01 is lower than K01 and K03, which have a thinner surface layer. This result is owing to the electrostatic enhancement of the newly developed filters. The K01, K02 and K03 are charged by corona discharging method. This is the reason why the collection efficiency of the K01 and K03 is higher than that of RF01 for particle size under 0.1 μm. In the case of K02, in spite of electrical charging, the efficiency is lowest. This is due to the thickness of the surface layer of the filter as mentioned before.

The electrically treated air filter media can reduce its thickness compared to that of untreated one. If the filter is much thinner like the case of the K02, however, the collection efficiency will be lower regardless of the electrostatic enhancement.

The filtration velocity also affects the collection efficiency, furthermore, the effects of the filtration velocity become greater as the filter is thinner and thinner. Fig. 6 shows the fractional collection efficiency of the K01, RF01, and RF02 filters. These figures show the typical filtration characteristics presented by Lee and Liu [1982a, 1982b]. The most penetrating particle size at which the minimum efficiency occurs becomes smaller as the filtration velocity increases.

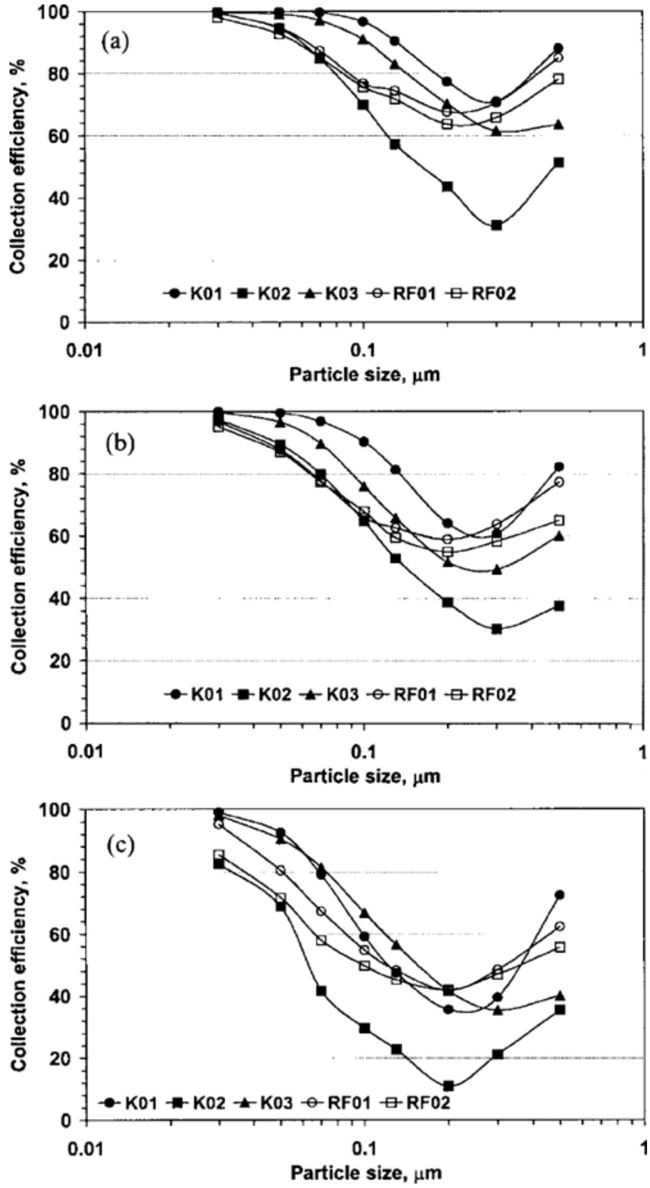

Fig. 5. Comparison of fractional collection efficiency of the tested filter media at various filtration velocities.
(a) V=1 m/min, (b) V=3 m/min, (c) V=10 m/min

In the Fig. 6(a), the efficiency decreases rapidly at V=10 m/min compared to other cases. On the other hand, the efficiency of the RF01 and RF02 filters at the same velocity is gradually reduced with a nearly constant decreasing ratio. Thus, the filter thickness must be determined under the consideration of filtration velocity required for a specific application.

SUMMARY

The three types of multilayer filter media were newly developed and evaluated for the purpose of application into turbine intake air filtration systems. The filtration performance of those filters was compared with that of existing filter media. For the multilayer filters tested in this work, the surface layer is mainly responsible for filtration efficiency. Especially, as a principal parameter for the multi-

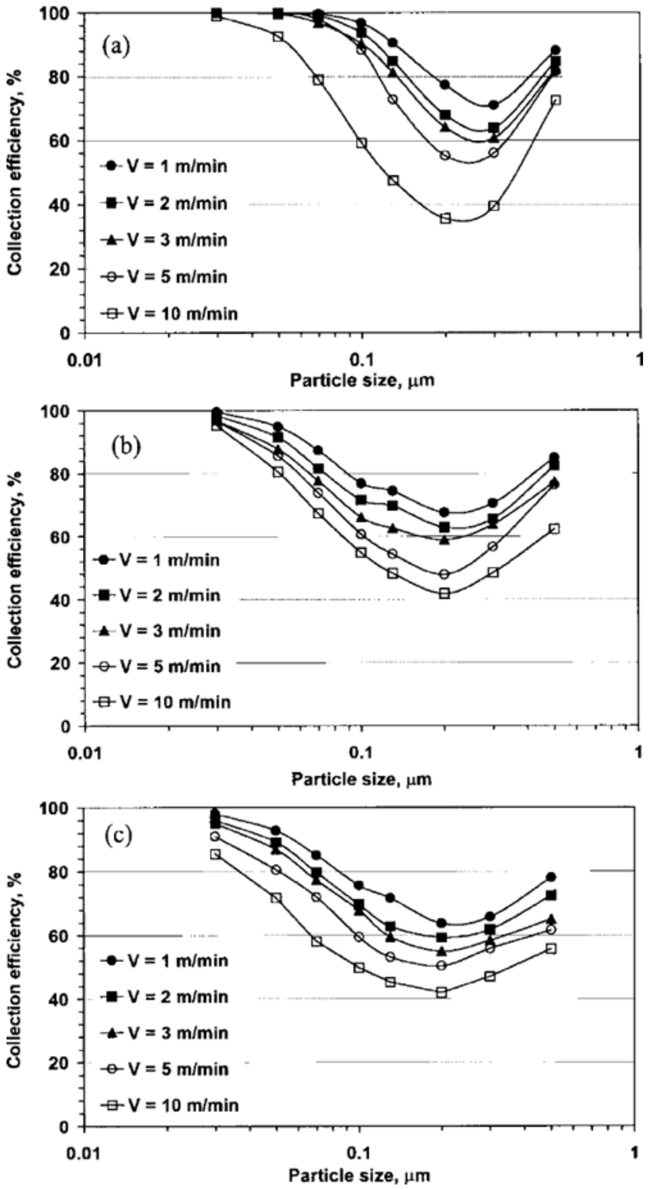

Fig. 6. Fractional collection efficiency at various filtration velocities.
(a) K01 filter media, (b) RF01 filter media, (c) RF02 filter media

layer filter design, the surface layer thickness greatly affects the pressure drop characteristics as well as the collection efficiency. Additionally, the surface layer thickness should be determined under the consideration of the filtration velocity applied and the electrostatic enhancement of filter media.

NOMENCLATURE

V : filtration velocity [m/min]
N : dust particle counts [-]

Greek Letter

η : fractional collection efficiency of a filter [%]

Subscripts

UP : upstream
DOWN : downstream

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