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Multidirectional evaluations of a carbon air filter to verify their lifespan and various performances

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ABSTRACT

Carbon air filter, called cabin filter, has been used to remove harmful airborne particles and gases causing human disease. This filter is composed of nonwoven and meltblown layers with activated carbons and is widely employed for such purposes as automobile air conditioning. Here, a fiber binder adapted cabin filter was prepared to simplify the fabrication process, enhance the economic benefits, and improve the filtration and gas adsorption efficiencies of the cabin filter. It exhibited higher filtration and gas adsorption efficiencies than a conventional liquid binder adapted cabin filter. Furthermore, multidirectional evaluations of the filtration efficiencies were performed considering various aerosol types, various particle sizes, inclusion or exclusion of electrostatics, various gas adsorptions of the filter unit, and lifespan expectation through dust feeding. A quality factor was introduced to substantiate the filter performance by considering the correlation between pressure drop and particle penetration. The optimal weight of the meltblown layer was first selected as 20 g/m^2, and it was confirmed that the mechanical and filtration properties of the fiber binder-adapted cabin filter were higher than those of a conventional cabin filter. An electro-charging effect was tested to demonstrate that it filled the efficiency vacancy under 1 μm and enhanced the filtration efficiency of the fiber binder adapted cabin filter compared with that of the uncharged cabin filter. Finally, the filter has a longer lifespan than the conventional one because it has more space to store dust. Overall, our research demonstrates a method to fabricate a fiber binder-adapted cabin filter and evaluates its performance via comprehensive evaluations.

1. Introduction

Many particles and volatile organic compounds (VOCs) generated naturally as well as deliberately are present in indoor air. They enter the body when a person inhales, then they reach the lungs and may even reside inside the body, causing lung cancer or chronic obstructive pulmonary disease (COPD) (Jo & Park, 1998; Lee & Zhu, 2014; Linders, Baak, Bokhoven, & Bokhoven, 2007; Muala et al., 2014). Therefore fiber-based filtration is easy and economical concept to overcome the harmful effects of particles and VOCs through their removal, numerous studies have been carried out focusing on simple fabrication steps and cost-down methods (Szekely,

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Jimenez-solomon, Marchetti, Kim, & Livingston, 2014; Wang & Otani, 2013). In particular, innovative nonwovens have been used in filter layers for several years; Nonwovens made from electrospinning or melt spinning have emerged as filtration media with a small pore size and high surface area (Hassan, Yeom, Wilkie, Pourdeyhimi, & Khan, 2013; Zuo et al., 2013). In addition, after activated carbons (ACs) were discovered as an effective material for controlling VOCs and removing contaminants and organic chemicals stemming from chemical adsorption (Dillon et al., 1997; Geiss, Tirendi, Barrero-Moreno, & Kotzias, 2009), AC-embedded air filters were used in ventilation fields; these filters were subsquently adopted for use in automobiles and became known as cabin filters.

The basic structure of cabin filters consist of a spunbond (SB) prefilter, a meltbrown microfilter (MB), ACs, and an SB substrate (from the inlet to the outlet). The SB prefilter and MB act as barriers to arrest coarse and ultrafine dust, respectively. Various materials, such as poly(lactic acid) (Liu, Cheng, & Cheng, 2010), polyurethane (Scholten, Bromberg, Rutledge, & Hatton, 2011), and high-strength poly(ethylene terephthalate) (PET) (Xu, Wang, Du, Zhang, & Wei, 2012), have been recently studied as novel MB filter units. Polypropylene (PP) is the representative material for an MB web because of its low cost and relatively easy processability (Luo, Stoyanov, Stride, Pelan, & Edirisinghe, 2012; Marla, Shambaugh, & Papavassiliou, 2009). ACs are evenly positioned between the MB and SB substrate using a binder material. In general, there are two correlation factors to determine the performance of an air filter, the pressure drop and filtration efficiency, where a low pressure drop and high efficiency are desirable for optimal air filters. The fabrication of the SB substrate and MB is a critical step for achieving these properties. The coarse layers are advantageous for achieving a low pressure drop; however, they lead to low filtration because their large pores do not effectively trap the nanoparticles. On the contrary, the dense layers show high filtration efficiency and lead to high pressure drop simultaneously which generates low airflow after filtration. Therefore, this behavior also has disadvantage that requiring the more energy to operate properly (Payet, Boulaud, Madelaine, & Renoux, 1992; Zhu, Qian, Lu, & Zhang, 2013).

Practicality must also be considered in regard to high filter performance. The adhesive strength between ACs and nonwoven layers is an important factor of manufactural durability. Liquid binder is typically used to help adhere the ACs and SBs because of its low cost and easy operation process, such as the spray system (Wang, Li, & Lu, 2010). However, several issues arise when employing an ideal binder material. Large amounts of binder cause a high pressure drop because they obstruct the pores of nonwovens, whereas insufficient amounts of binder lead to a decreased adhesion strength between ACs and SBs. A decreased adhesion strength reduces the gas adsorption efficiency, as it is critical to prevent ACs from escaping at the edge of the filter. Although thermal pressing process and sewing the edge of the filter media are the effective ways to prevent ACs escaping, these post-treatment processes require additional time, labor, and cost (Abgrall, Low, & Nguyen, 2007; Rodionov, Doriomedov, & Makarova, 2013; Saad & El-newashy, 2011).

To resolve these problems, fiber binder is suggested in this study instead of a conventional liquid binder for an easy and fast fabricating process maintaining high performance. The fiber binder is expected to help strengthen the adhesive strength between filter layers. A scheme of our research is shown in Fig. 1. In addition, various measurements were performed to comprehensively determine the cabin filter performance. Numerous studies have conducted fragmentary performance evaluations of cabin filters employing, for instance, particle filtration or gas adsorption analyses (Gallego, Roca, Perales, & Guardino, 2013; Park, Yoon, Noh, Byeon, & Hwang, 2010). This study determined the performance of a fiber-type binder and conducted a multidirectional evaluations

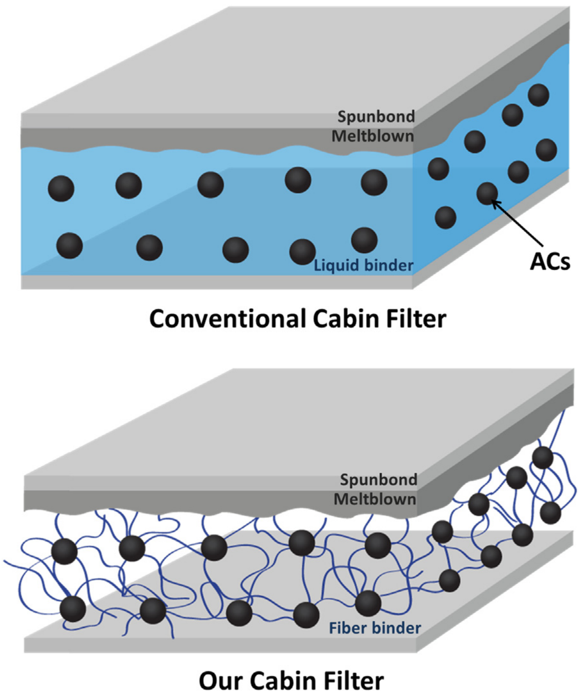

Fig. 1. Scheme of conventional liquid (top) and fiber binder-based carbon air filter unit (bottom).