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CHARACTERIZATION OF INDUSTRIAL FILTRATION SYSTEMS FOR FINE PARTICLE

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ABSTRACT

Environmental regulation for fine particle in Korea is based on the emitted mass per unit volume. Thus, industrial plants that emit large quantities of dust are not concerned with fine particles such as PM (particulate matter) 2.5 and PM 10; as fine particles, compared to large particles, do not cause a significant effect on the total emitted mass. However, fine particles must be controlled, as there are increasing concerns about these particles worldwide. In this study, removal efficiency for fine particles by industrial filtration systems was experimentally measured. The most common industrial filtration system is a bag filter, with two different types of materials characterized in terms of the efficiency. Based on numerous experiments, the removal efficiency of glass fiber material was superior to that of polyester material. In addition, several expiriments were later conducted to explain these results.

Keywords: fine particle, removal efficiency, filtration, bag filter.

INTRODUCTION

As industry evolves, we are experiencing more serious environmental problems. Fine particle is considered as one of the problems and is a cause of cancer according to World Health Organization (WHO). Thus, there have been numerous studies to maximize particle removal efficiency from operating fluid.

In (Stephens and Siegel, 2013), (Jamriska, Morawsaka, and Ensor, 2003) the authors studied the removal of indoor fine particles and comparisons between indoor ventilation and filtration. (Jamriska, Morawsaka, and Ensor, 2000). Other research for removing indoor microbes using a high-efficiency particulate air (HEPA) filter was also conducted by (Chuaybamroong *et al*., 2010). (Fisk, 2013), (Buchanan *et al*., 2008) conducted studies about filtration of other hazard materials such as ozone and nitrogen oxide and also health benefis of those materials' filtration.

The most common means of removing industrial fine particles from plant's and steelworks' operating fluid is the bag filter. A study for manufacturing and selecting of bag filter using non-woven fabric was conducted by (Lee, 2013). (Choi and Koo, 2007) conducted a numerical simulatioin to characterize flow in the reactor of an integrated adsorption and catalysis process with bag filters. In (Lee *et al.*, 2006) the authors determined the effect of foaming parameters such as feeding and mixing velocity of coating fluid on bag filter performance. (Park, 1995) studied enhancement of industrial bag filter by applying actual operation conditions for the filter in power-plants. Particle removal efficiency with fabric for bag filter was experimentally determined for several filtration velocities by (Salazar-Banda *et al.*, 2012). (Lee and Seo, 2008) studied the enhancement of bag filters against hazardous gas. (Tsai, C., Tsai, M., and Lu, 2000) determined effect of filtration velocity and filtration pressure drop in bag cleaning process. (Park, Roh, and Lee, 2008) compared dust filtration performance with and without pleated configuration in cybagfilter. The method for minimizing particle losses from bag filters, carbon filters, and combination was studied by (Bekc, Clausen, and Weschler, 2008). Electrostatic cyclone-bag filter was optimized for aerosol's charging methodology. (Lee and Yoa, 2000).

Polyester and glass fiber are the most commonly used materials. However, performance of bag filters with those materials has not been fully characterized. Thus, in this study removal efficacies of polyester and glass fiber bag filters were studied as a function of particle size and also filtration velocity. In addition, studies with scanning electron microscope and capillary flow poremeter were conducted to provide supporting documentation of results.

EXPERIMENTAL METHODOLOGY

Experimental setup and procedure

As shown in Figure-1, a square wind tunnel was used to quantify the removal efficiency for fine particles. Test section of the wind tunnel was 0.62m×0.62m and Figure-2 shows a set of installed bag filters in the test section of the tunnel. Filtration velocity was varied by frequency of a motor. Filtration velocity is not flow velocity, but a ratio of total volume flow rate to total surface area of bag filter. In other words, the filtration velocity could be significantly lower than flow velocity. It is important to inject the same amount of dust into the wind tunnel each experiment so that the amount of dust would not be a variable. To do so, a micro-balance (Model: EL303, Toledo, OH, USA) was used to weigh the dust.

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Dust was injected from the top-left in Figure-1 and traveled through the tunnel. Optical particle counters (Model: HCT 1.109, GRIMM, GA, USA) upstream and downstream of the filter measured particle concentration at both locations. Removal efficiency for a filter is calculated by following the equation.

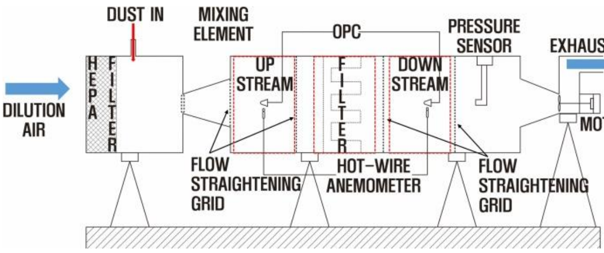

Figure-1. Schematic of square wind-tunnel.

Figure-2. A set of installed glass fiber bag filter in wind-tunnel.

Particle Removal Efficiency (1)

$$= \left(1 - \frac{Particle\ concentration\ at\ downstram}{Particle\ concentration\ at\ upstream}\right) \times 100$$

Introduction of polyester (PE) and glass fiber (GF) filter Table-1 summarizes basic specifications of polyester and glass fiber bag filters. Glass fiber is suitable for large amounts of air sampling for gravimetric analysis and air quality assessment. Additionally, heat-resistance of glass fiber is remarkable. Polyester is excellent for acid and alkali resistance, mechanical strength, and durability.

RESULTS AND DISCUSSIONS

Characterization of horizontal wind-tunnel

Since the wind-tunnel is horizontally operated, it was important to verify that the momentum of low flow velocity in the tunnel was strong enough to carry large particle such as 10 micro-meters or larger through the tunnel without significant deposition. Tested flow velocities were 0.02 and 0.5 m/s. One of project's goals was to determine the removal efficiency at different filtration velocities. The velocity lower and upper limits were 50% and 150% of 0.7058 meter/min (mpm), standard condition in the field, respectively. The range of flow velocities corresponded with the filtration velocity limits. For this test, particle concentrations upstream and downstream of filter location (Figure-1) were compared, however no filter was installed between the two particle counters.

Table-1. Specification of polyester and glass fiber.

	Area weight (g/m^2)	**Thickness** (mm)	**Air permeability** (mm/s @200 Pa)	**Tensile strength** (N)	**Temperature resistance** (°C)
GF	770	0.9	25-75	3500	260
PE	600	1.7	133	1650	120

Figure-3 displays particle number concentration upstream and downstream for the particle size range from 0.25 to 40 micro-meters when flow velocity was 0.5 m/s. This showed almost no detected particle beyond 8 micro-meters. There was less than 10% difference for particle concentration between the locations in the range from 0.25 to 6.5 micro-meters. The author paid more attention to the case of 0.02 m/s as the flow velocity is significantly lower than that of 0.5 m/s. Figure-4 shows particle number concentration upstream and downstream when flow velocity was 0.02 m/s. There was a clear trend for the concentration downstream to be lower than that of upstream. The difference in the concentration deposition was due to relatively small flow velocity momentum. Since the difference in the whole particle size range in Figure-4 was similar, an overall correction factor of 1.16 in the whole size range was applied when calculating removal efficiency for the bag filter.

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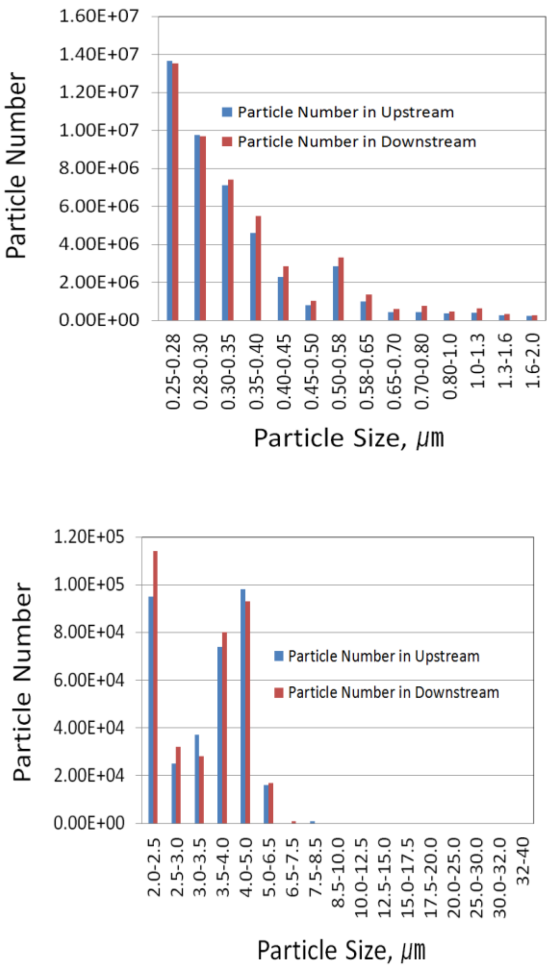


Figure-3. Particle number concentration at upstream and downstream when flow velocity was 0.5 m/s.

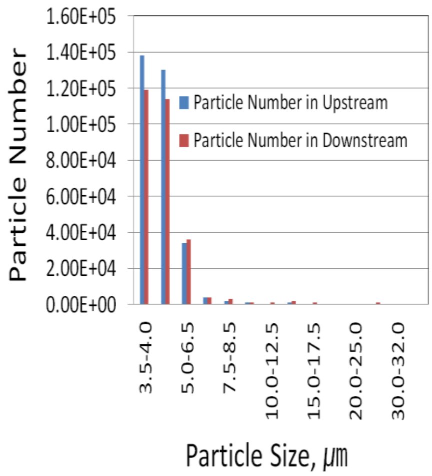


Figure-4. Particle number concentration at upstream and downstream when flow velocity was 0.02 m/s.

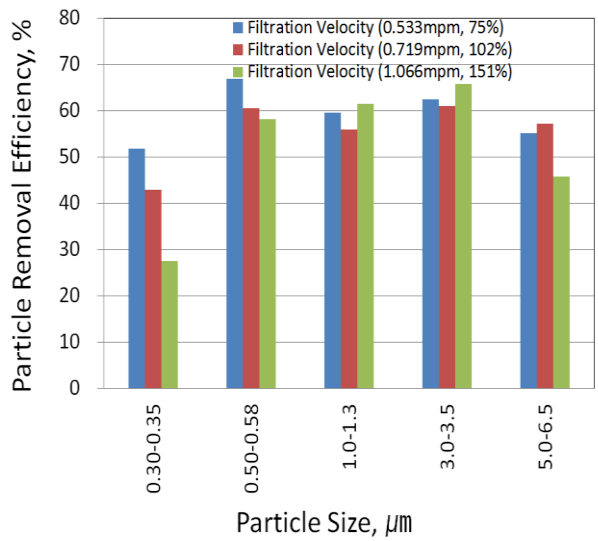
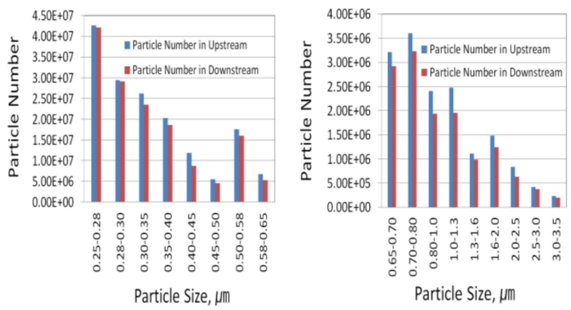


Figure-5. Particle removal efficiency of polyester filter as a function of particle size.

Removal efficiency for polyester Bag filter

Polyester bag filter efficiency was tested in a wind-tunnel with identical parameters of those in Figure-2. The removal efficiency as a function of particle size is shown in Figure-5. In the legend, the percentage is based on 0.7058 mpm. The efficiency was around 50 to 60% and appears to be neither a function particle of size, nor filtration velocity in the tested range.



Removal efficiency for glass fiber Bag filter

Figure-6 displays particle removal efficiency for glass fiber bag filter with different filtration velocities and particle sizes. The filter removed almost 100% particles, larger than 7.5 micro-meters. The effieicny was between 90 to 100% for the particle size from 5 to 6.5 micro-meters, and 80 to 90% from 0.5 to 3.5 micro-meters when the filtration velocities were between 0.333 to 0.833 mpm. Efficiency tended to decrease as filtration velocity increased and particle size decreased.

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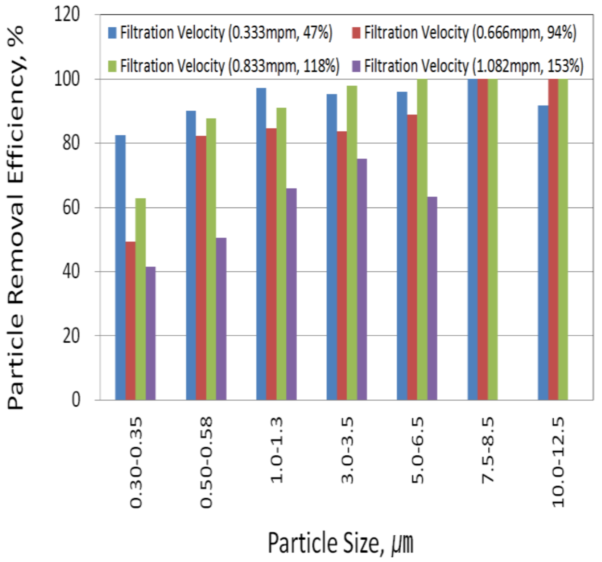

Figure-6. Particle removal efficiency of glass fiber filter as a function of particle size.

Comparison of polyester and glass fiber bag filter

Performance of polyester and glass fiber bag filters was compared and shown in Figure-7. Filtration velocities were different at 0.719 and 0.833 mpm for polyester and glass fiber bag filter, respectively. However, particle removal efficiency with glass fiber filter was significantly higher than that with polyester filter. There were approximately 40% and 20~30% efficiency difference for the particle size from 3 to 6.5 micro-meters and from 0.5 to 1.3 micro-meters, respectively.

Two analysis were excuted to verify the difference in the removal efficiency with two bag filters. The first analysis from a scanning electron microscope used a

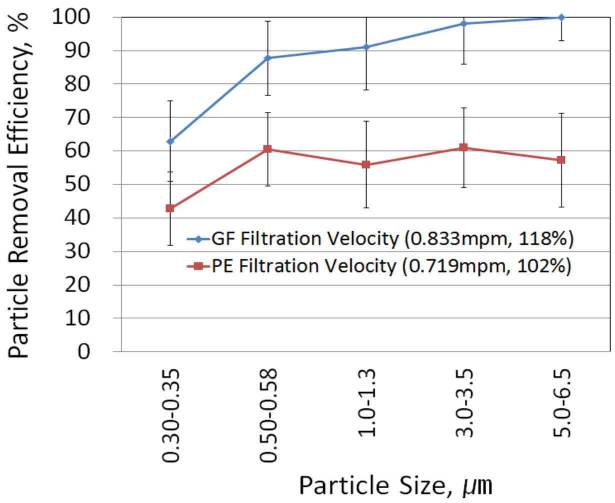

Figure-7. Comparison of glass fiber filter with polyester filter at the similar filtration velocity.

focused beam of electrons to generate images of each filter. Figure-8 shows photos of the two materials; the left photo is polyester and the right one is glass fiber. Notice the 10 micro-meters ruler at the right-bottom of each photo; the ruler in the right photo is approximately twice as long as the ruler in the left photo. However, the fiber in the right photo is significantly denser than that in the left photo. The images from scanning electron microscope qualitatively explain about "Why the removal efficiency with glass fiber bag filter was higher than that with polyester bag filter".

The second analysis was measuring pore sizes by using a capillary flow poremeter (Porous Material Inc., NY, USA) whose principle is as follows;

"A wetting liquid called 'Galwick' spontaneously fits the pores of a sample. Then differential pressure of a non-reacting gas on the sample is applied to remove the wetting liquid from pores. The removed liquid is the pore size".

Table-2 shows maximum and average pore sizes for polyester and glass fiber. Both maximum and average pore sizes with polyester are significantly larger than those with glass fiber. This result quantitatively explains the results in Figure 5-7.

Table-2. Pore size of polyester and glass fiber.

	Maximum pore size (μm)	**Average pore size** (μm)
Polyester	44	13.7
Glass fiber	8.4	1.1

Theoretical calculation for the amount of emitted particle

Actually generated fume from a steel-works in Korea was analyzed to determine its particle distribution. Figure-9 displays individual particle distribution of the fume.

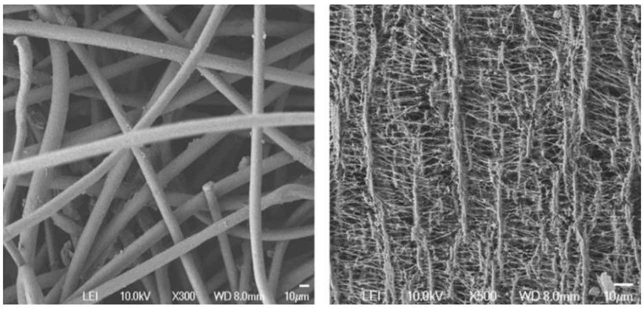

Figure-8. Photo of scanning electron microscope. (L) Polyester, (R) Glass fiber.

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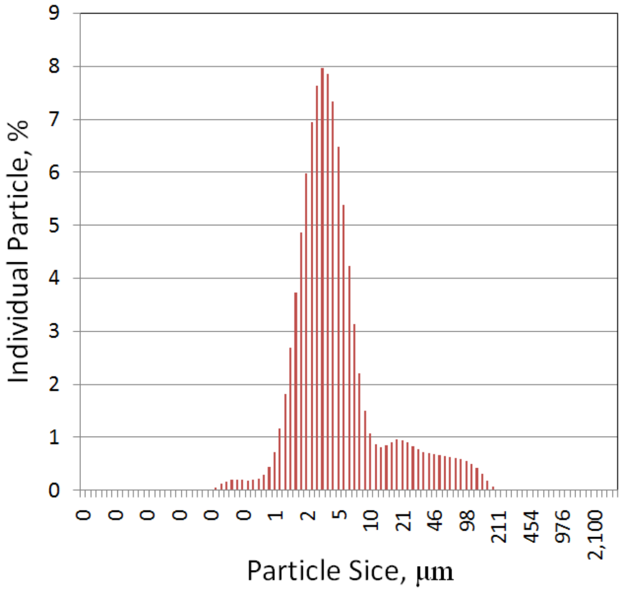

Figure-9. Individual particle distribution of fume from a steel-works as a function of particle size.

Figure-10 shows cumulative distribution based on both number and volume. Approximately 3.8 and 115.8 micro-meters were number and volume median particle diameters, respectively.

Amount of minimum and maximum emitted fume from the steel-works were 225.5 and 900.2 mg/m^3, respectively. Table-3 is a result for calculated emitted mass. Polyester filter would not meet the emission requirement that is currently 50 mg/m^3 even in case of the minimum amount of fume. However, emitted particle masses after glass fiber filter were 0 mg/m^3 regardless of the mass before the filter. This is because volume median particle diameter was 115.8 micro-meter and glass fiber filter removed 100% particles, larger than 7.5 micro-meters.

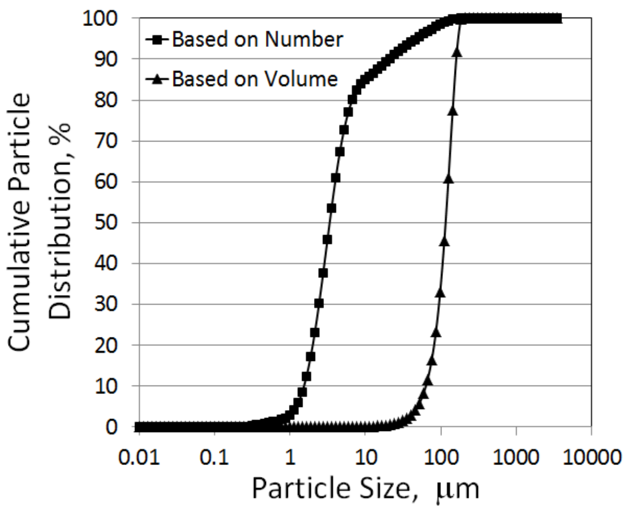

Figure-10. Cumulative particle distribution of fume in Figure-9 based on number and volume.

Table-3. Emitted particle mass.

Fume mass concentration before filters, mg/m^3	Fume mass concentration after GF filter, mg/m^3	Fume mass concentration after PE filter, mg/m^3
225.5	0	97.7
900.2	0	378.1

CONCLUSIONS

In this study, two different materials used in industrial bag filters were tested for their particle removal efficiency in terms of particle size and filtration velocity. Experimentation was conducted using a horizontally operated square wind-tunnel that was fully characterized for particle deposition at low flow speed. The glass fiber bag filter removed 100% of particle larger than 7.5 micro-meters at most filtration velocities with polyester bag filters performing significantly lower at approximately 50 to 60% regardless of tested particle sizes and filtration velocity. The results were supported by data from a capillary flow poremeter and scanning electron microscope. Maximum and average pore size of polyester bag filter was 44 and 13.7 micro-meters, respectively. The degree of density for the two materials was qualitatively compared by using a scanning electron microscope; with the glass fiber being significantly denser than the polyester.

It turned out that two most widely used commercial bag filters were not sufficient to complete remove fine particles smaller than 10 micro-meters. Particle size statistics was employed for theoretical calculation to estimate the amount of particle emission after two filters by using actual fume from a steel-works. Polyester failed for the current regulation and glass fiber met the requirement. However, what if the environmental regulation is changed towards particle sizes, such as PM 10 and PM2.5? If this regulation is changed, glass fiber

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filter is not the right candidate anymore as it emits more than 50% of particle based on its number.

In future work, the author of this paper will propose an alternative to filtration bags that will be 99% efficient for removing particles larger than 2.5 micro-meters based on CFD (computational fluid dynamics.) Another goal will be to satisfy power consumption, which must be the same or lower than what is required to operate a bag filtration system, at the same flow rate.

REFERENCES

Bekc G., Clausen G. and Weschler C. J. 2008. Sensory pollution from bag filters, carbon filters and combinations. Indoor Air. 18(1): 27-36.

Buchanan I. S. H., Mendell M. J., Mirer,A. G. and Apte M. G. 2008. Air filter materials, outdoor ozone and building-related symptoms in the base study. Indoor Air. 18(2): 144-155.

Choi C. R. and Koo Y. S. 2007. Numerical analysis on flow characteristics in the reactor of an integrated adsorption/catalysis process with bag filters. Journal of Korean Society for Atmospheric Environment. 23(2): 203-213.

Chuaybamroong P., Chotigawin R., Supothina S., Sribenjalux P., Larpkiattaworn S. and Wu C. Y. 2010. Efficacy of photo catalytic hepa filter on microorganism removal. Indoor Air. 20(3): 246-254.

Fisk W. J. 2013. Health benefits of particle filtration. Indoor Air. 23(5): 357-368.

Jamriska M., Morawsaka L. and Clark B. A. 2000. Effect of ventilation and filtration on submicron meter particles in an indoor environment. Indoor Air. 10(1): 19-26.

Jamriska M., Morawsaka L. and Ensor D. S. 2003. Control strategies for sub-micrometer particles indoors: model study of air filtration and ventilation. Indoor Air. 13(2): 96-105.

Lee C. J. 1995. Manufacture and selection of bag filter. Journal of Korean Membrane Society. 5(2): 59-64.

Lee S. J. and Seo M. C. 2008. A study on the Improvement of dry bag filter treatment system regarding harmful gas of glass recuperator. Journal of Environmental and Sanitary Engineering. 23(3): 9-22.

Lee M. H., Kim Y. C., Lee S. J., Kim S. B. and Kim K. S. 2006. Effect of foaming parameters on the performance of a surface coating bag-filter media. Journal of Korean Society for Atmospheric Environment, Korea, Chuncheon. pp. 243-245.

Lee W. H. and Yoa S. J. 2000. Characteristics of electrostatic cyclone-bag filter with upper inlet. Journal of Korean Society for Atmospheric Environment. 16(2): 179-189.

Park Y. O. 1995. Operation and performance of industrial bag filter apparatus. Journal of Korean Membrane Society. 5(1): 16-25.

Park Y. O., Roh H. J. and Lee Y. W. 2008. Dust filtration characteristics of pleated filter bags installed in cybagfilter. Journal of Korean Society for Atmospheric Environment. 24(4): 483-491.

Salazar-Banda G. R., Lucas R. D., Coury J. R. and Aguiar M. L. 2012. The influence of particulate matter and filtration conditions on the cleaning of fabric filters. Separation Science and Technology. 48(2): 223-233.

Stephens B. and Siegel J. A. 2013. Ultrafine particle removal by residential heating, ventilating, and air-conditioning filters. Indoor Air. 23(6): 488-497.

Tsai C. J., Tsai M. L. and Lu H. C. 2000. Effect of filtration velocity and filtration pressure drop on the bag-cleaning performance of a pulse-Jet baghouse. Separation Science and Technology. 35(2): 211-226.