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A Study on the Effect of Dust Precharging on Filtration Performance

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Abstract

A hybrid dust-collector combining electrostatic charging with fabric filtration method was developed, and its performance characteristics were evaluated in this study. Charged particles build porous dendritic structure on the surfaces of filter by electrostatic attraction, increasing the collection efficiency of dust particles and reducing the pressure drop through the deposited dust layer and filter media. The cleaning performance of the dust layer is improved because the dendritic structured dust layer can be removed more easily by pulse jet cleaning flow. The results of the experiment showed a reduction of fine particle emission of 37% and the energy saving of 13% by precharging dust particles before filtration.

Key words : Fabric filter, Electrostatic, Precharge, Pressure drop, Collection efficiency, Dendritic structure

1. INTRODUCTION

The bag filter is one of the most widely used air pollution control units in industry due to its stability of operation and high efficiency (McIlvaine, 1995). Although its demand is still increasing, the fabric filtration method has some disadvantages such as low efficiency for fine dust particles and high operation cost caused by high pressure drop. Especially fine dust particles cause the pore blockage of fabric filter, increasing the pressure drop across the filter and shortening its life.

In order to solve these problems, some researches have attempted to combine one or more dust collection mechanisms such as centrifugal separation or electrostatic precipitation with fabric filtration in a system so far (Son *et al.*, 1998).

This research aimed to develop a hybrid filtration system combining electrostatic dust precharging with fabric filtration for lowering the pressure drop and dust emission of fabric filter.

There are some dust charging mechanisms such as static electrification, diffusion charging, and field charging. The last two require high concentrations of unipolar ions. Because of the mutual repulsion and high electrical mobilities of those ions, their lifetime is short. To make up for this problem, corona discharging was commonly introduced to continuously produce unipolar ions at high enough concentration to be useful for dust charging (Hinds, 1999).

A dust charged in corona discharge fields is usually captured on the surface of filter media and forms a porous dendritic structured layer, because electric

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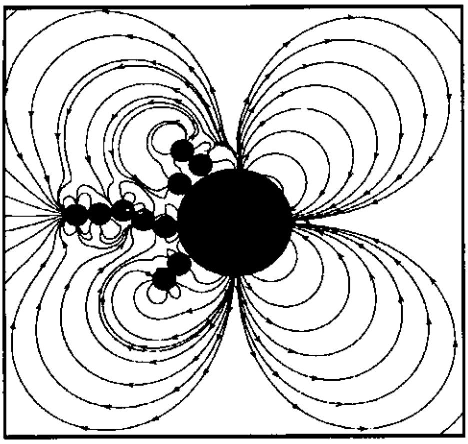


Fig. 1. Electric field around the captured particles.

fields tend to concentrate on the end point of dust particles captured previously as shown Fig. 1 (Park *et al.*, 1999). The dust layer formed in that manner makes pressure drop across the dust layer low, and collection efficiency high due to reinforced collection mechanism with electrostatic force (Ramb, 1976).

2. EXPERIMENTAL

2. 1 Dust precharger

The dust precharger for charging dust particles consists of multiple saw type discharge electrodes and plate type ground electrodes with a space of 30 mm between each electrode as shown in Fig. 2. This precharger is designed to produce the non-pulsed negative corona for effective and stable operation and made.

The dust precharger is located at the inlet of filter chamber as a united body of filter unit to minimize losing electrostatic charges of dust and dust depositing at the wall of inlet duct on the way to the filter.

2. 2 Test filter

Test filter was manufactured by coating the filter surface with porous acrylic polymer for the surface filtration. Nonwoven polyester fabrics were used as supporting materials. The total 16 bag filters of 156 mm in diameter and 2,500 mm in length are installed in the test chamber.

2. 3 Experimental setup

Fig. 3 shows the schematic diagram of experimental setup. The experimental setup consists of a dust supplying and dispersing part for controlling inlet dust concentration, a precharging part for dust charging, a fabric filter unit (baghouse) for evaluating the filter performance, an air suction and flow controlling part, compressed air supply system for filter cleaning, and data acquisition unit.

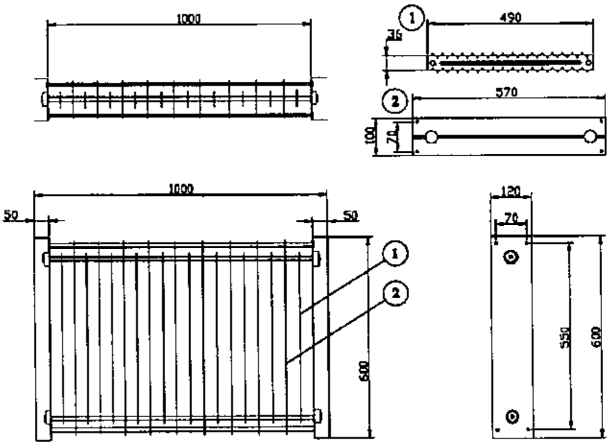
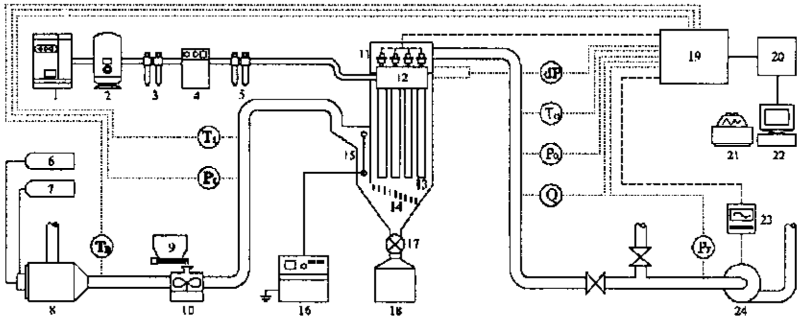


Fig. 2. Dust precharger.



1. Air compressore
2. Air tank
3. Pre-filter
4. Air dryer
5. Final filter
6. Fuel oil
7. LP gas
8. Hot gas generator
9. Test dust feeder
10. Dust disperser
11. Solenoid valve
12. Pulse air header
13. Bag filter
14. Ladder vane baffle
15. Dust ionizer
16. High voltage generator
17. Rotary valve
18. Portable dust box
19. Main control box
20. A/D converter
21. Printer
22. Computer
23. Phase inverter
24. Exhaust fan

Fig. 3. Schematic diagram of experimental setup.

The fabric filter unit has a pulse-jet cleaning module for filter cleaning. The maximum flow capacity of the fabric filter unit is 60 m^3/min.

2. 4 Experimental procedure

In order to evaluate the effects of dust precharging on the performance of bag filter, the pressure drops and dust collection efficiencies of bag filters were measured with uncharged and charged dust particles, respectively. The mass concentrations and size distributions of dust particles at the inlet and outlet were measured using Aerosizer (Mach-LD, API).

The lime particles flew off during crushing and conveying process of limestone were used as test dust. The dust particles were fed continuously into the inlet duct with the mass concentration of 180 mg/m^3 by volumetric screw feeder.

Fig. 4 shows the relationship between the discharge current of precharger and the amount of particle charge for lime dust. The amount of dust charge was measured using Aerosol Electrometer (3068A, TSI Inc.). Since the discharge current increased very rapidly above -8 kV whereas the amount of dust charge increased no more, the applied voltage was kept as -8 kV for the dust charging condition. That the amount of

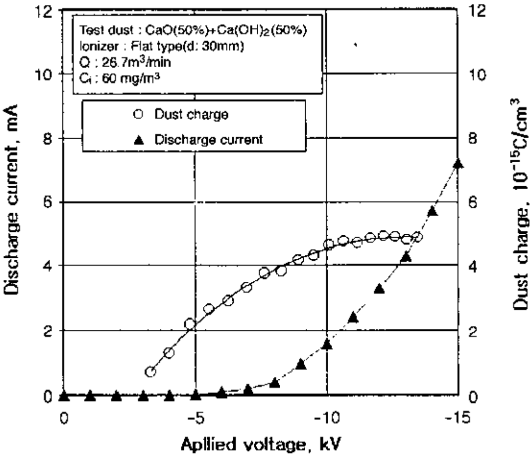


Fig. 4. Discharge and dust charge characteristics of dust precharger.

Table 1. Test conditions.

Test dust	Lime dust
Filtration velocity	1.36 m/min
Inlet dust concentration	180 mg/m^3
Temperature	ambient condition
Applied voltage (when precharged)	-8 kV
Test filter	L-MEMFIL™
Cleaning onset base (?P of filter)	100 mmH$_2$O
Cleaning air pressure	5 kg$_f$/cm^2
Cleaning duration	120 msec

dust charge does not increase any more above −8 kV is not because the dust particles are fully saturated with charges, but because the precharger reaches to its upper limit of performance by dust residence time in it.

The overall test conditions were summarized in Table 1.

3. RESULTS AND DISCUSSION

3. 1 Pressure drop

Fig. 5 shows the pressure drop across the filter for the case of uncharged and charged dust particles. As shown in this figure, increasing rate of the pressure drop is reducecd by 35% in the charging condition than in the uncharging condition. Also, the average cleaning interval is prolonged about twice when the particles are charged. This may be caused by the attachment of dust to the wall of filter casing and by the formation of a porous dust layer with dendritic structure at the filter surface due to the electrostatic force between charged particles.

Residual pressure drop after filter cleaning is lower about 24% for the charging condition than for the uncharging condition. This is because charged fine particles are agglomerated with dendritic structure by the electrostatic force, which prevents clogging the pores of filter media. Since the filter performances such as cleaning interval and residual pressure drop are directly related with filter lifetime, it is reasonable from the results that the filter lifetime can extend about twice as much by applying electrostatic dust charging method to the fabric filter system.

3. 2 Dust collection efficiency

Fig. 6 shows fractional collection efficiencies for the case of charged and uncharged dust particles. For both cases, collection efficiency has a minimum value at the particle size of around 0.6 μm. The collection efficiency for the charged particles is about 4% higher than for the uncharged ones. This is significant improvement considering the fact that submicron particles are most hazardous to human health.

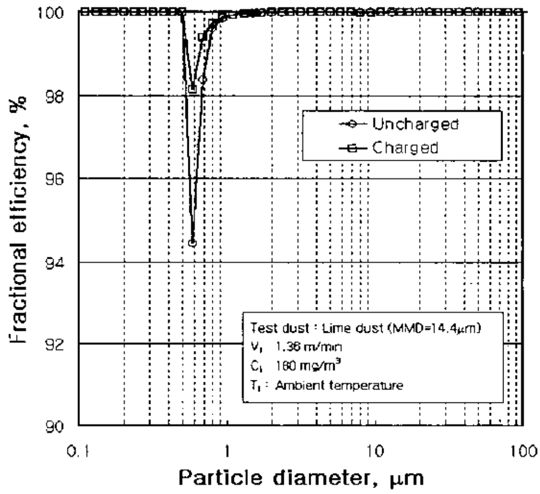
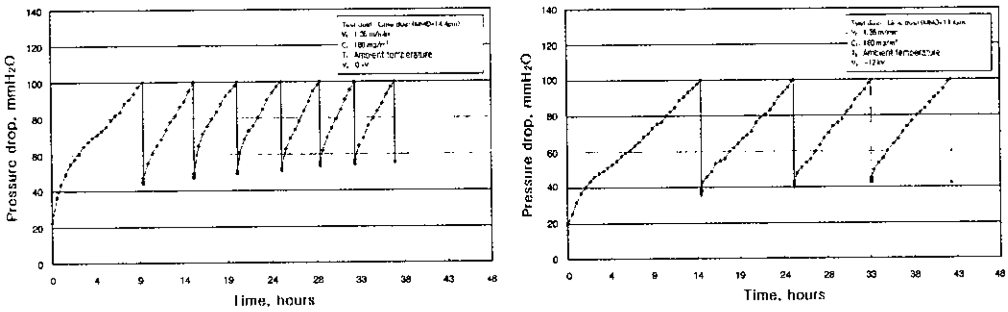


Fig. 6. Fractional dust collection efficiency.



(a) uncharged

(b) charged

Fig. 5. Pressure drop of bag filter.

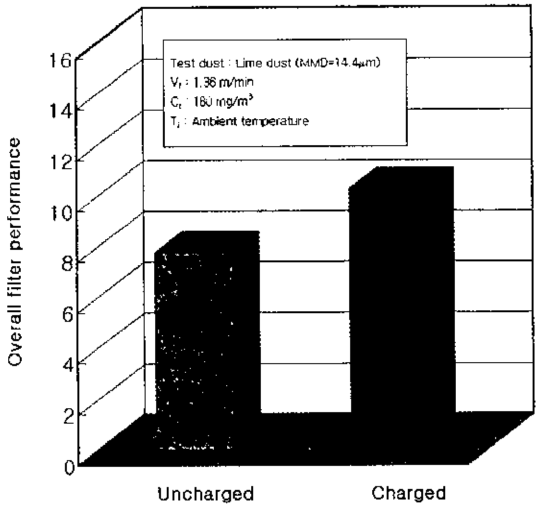


Fig. 7. Filter performance.

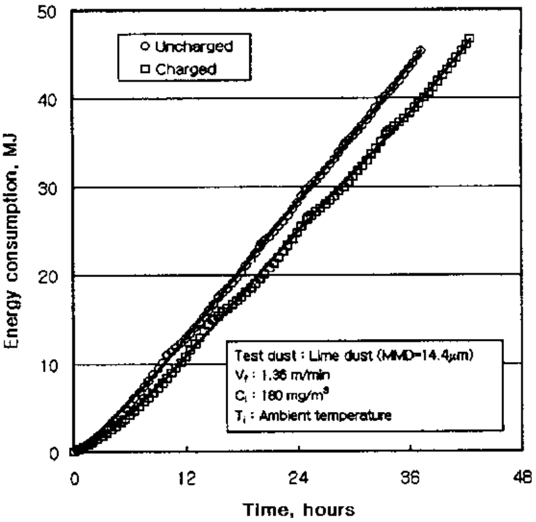


Fig. 8. Total energy consumption.

The total penetration of PM2.5 for the charging condition is 37% lower than for the uncharging condition. It is noteworthy that the improvement of dust collection efficiency by electrostatic charging is effective especially for the fine particles.

The overall dust collection efficiencies are higher than 99.99%, and dust penetrations are extra low under both conditions. However, the overall dust penetration through the filter media for the charging condition is reduced to 97% of that for the uncharging condition.

3. 3 Filter performance

With quantitative measures of a balance between collection efficiency and pressure drop of filters, filter performance value is frequently estimated. This value is defined by the following Equation (1).

$$FP = -\frac{\log(\mathrm{P}[\%]/100)}{\Delta P[\mathrm{mmH_2O}]} \times 100 \qquad (1)$$

Here, P is the dust penetration and ΔP is the pressure drop across the filter. The higher the filter performance value, the higher the dust collection efficiency and the lower the pressure drop of filters.

Fig. 7 compares the filter performance value for the charging and the uncharging conditions. The filter performance value for the charging condition is shown to be 32% higher than that for the uncharging condition. This is because both the cleaning and the collection efficiency of the filter are improved by dust charging.

3. 4 Energy consumption

Fig. 8 compares the total energy consumption for the charging and the uncharging conditions. The total energy consumption is the sum of the energy required for suction of gas, that for air compression necessary to filter cleaning, and that for dust charging. The energy for gas suction was calculated using the measured pressure drop, filter area, and gas flow rate. The energy for filter cleaning was obtained by the estimation of the air compression as a polytropic process to compensate the pressure deviation between just before and after cleaning (VanWylen and Sonntag, 1986). Precharging energy was calculated using the voltage and current applied to the precharger. The equations used to calculate the energy consumption are as follows.

$$E_{fan} = \Delta P(t) \cdot A_{filter} \cdot t \qquad (2)$$

$$E_{comp} = N \cdot \frac{(P_2 - P_1) \cdot V_{header}}{(1-n)} \qquad (3)$$

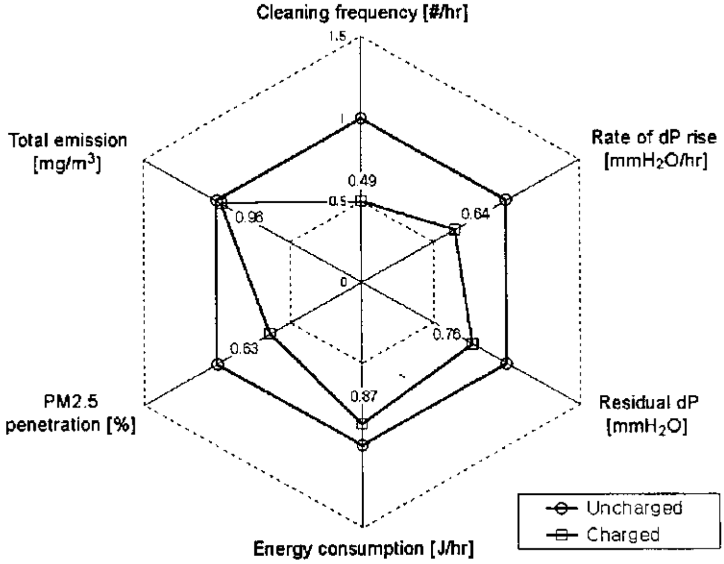


Fig. 9. Comparison of the results of uncharged and charged conditions.

$$E_{charge} = V \cdot I \cdot t \quad (4)$$

Here, ΔP is the pressure drop of the filter, A_{filter} is the filtration area, t is the operating time, N is the number of cleaning, P_1 and P_2 are the pressure of reservoir just before and after cleaning, respectively, n is the exponent for polytropic process, V_{header} is the volume of reservoir, V is the applied voltage, and I is the applied current.

From the calculation, the energy for gas suction was the highest and the relative portion of the energy for filter cleaning increased as the cleaning process proceeded. As shown in the figure, the case of dust charging consumed 13% less total energy, although additional energy was required for dust charging to decrease the residual pressure drop and the number of filter cleaning per unit time.

Fig. 9 shows the summarized results of these experiments. In this figure, the values represent the relative filter performances for the charging condition, supposing those of the uncharging condition as 1. From this comparison, it can be concluded that the dust precharging does a great deal for the improvement of overall filter performances, especially for the extension of cleaning interval and the increment of the collection efficiency of fine dust particles.

4. CONCLUSIONS

A hybrid dust-collector combining electrostatic charging with fabric filtration was developed and its performance characteristics were evaluated.

For the dust charging condition, the average cleaning interval was prolonged about twice as much and the residual pressure drop after filter cleaning was reduced by 24% than those for the uncharging condition. This is because the dust attaches to the wall of filter casing and forms a porous dust layer with dendritic structure on the filter surface due to the electrostatic effect of charged particles.

Since the filter performance such as cleaning interval and residual pressure drop is directly related to the filter lifetime, it is reasonable from the results that the filter lifetime can be extended about twice as much by applying electrostatic dust charging method to the fabric filter system.

Improvement of dust collection efficiency by electrostatic charging is found so effective especially for fine particles. In facts, the penetration of PM2.5 under the charging condition was found to improve by 37% compared with that for the uncharging condition.

The case of dust charging consumed 13% less total energy although additional energy was required for dust charging to decrease in the residual pressure drop and the number of filter cleaning per unit time.

NOMENCLATURE

A_{filter} : Filtration area, [m^2]
E_{charge} : Energy for corona discharge, [J]
E_{comp} : Energy for air compression, [J]
E_{fan} : Energy for gas suction, [J]
I : Current applied to dust precharger, [A]
N : Number of filter cleaning, [-]
n : Exponent for polytropic process, [-]
P : Dust penetration, [%]
P_1 : Air pressure in reservoir just before cleaning, [Pa]
P_2 : Air pressure in reservoir just after cleaning, [Pa]
FP : Filter performance value, [-]
ΔP : Pressure drop of filter, [mmH_2O]
T : operating time, [sec]
V_{header} : Volume of air reservoir (header), [m^3]
V : Voltage applied to dust precharger, [V]

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