Article

Filtration Performance Characteristics of Sticky Aerosol Using Calcium Hydroxide

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Abstract: This study examined the performance of removing aerosol upon a flow rate variable by agglomerating sticky aerosol with calcium hydroxide and removing cohesive aerosol through an experimental apparatus, simulating an actual painting booth. As a result of examining the performance of the filter by fixing the paint spray quantity, the calcium hydroxide input and the filtration area under variable flow rates of 5, 10, and 15 Nm³/min, we confirmed that the filter performance has long average aerosol removing intervals at the 5 Nm³/min flow rate. At the 5 Nm³/min flow rate, there is a low residual pressure drop trend and high fractional collection efficiency, and a high level of total collection efficiency is maintained at 99.42%. When the flow rate is less than 5 Nm³/min, the aerosol settling and experimentation was impossible. With this research, the optimal conditions for the use of sticky aerosol have been examined.

Keywords: sticky aerosol; calcium hydroxide; flow rate; filter; total collection efficiency

1. Introduction

As air pollutants without known causes have been generated, and as human beings, the ecology, and nature are damaged with the rapid industrial development of the modern era, research on air pollution protection facilities has been carried out [1]. There are places that have been found to have various air pollutants, in which the emission of sticky aerosol and gaseous substances from painting booths such as VOCs (Volatile Organic Compounds) is a very serious problem [2,3]. A number of studies has been concerned with the removal of VOCs as gaseous substances from painting booths, but it is rare to find research on practically removing large quantities of sticky aerosol [4,5]. A method to remove aerosol generated from normal industrial sites is to collect it with a filter, remove the aerosol, and capture it using a hopper [6]. It is difficult to manage sticky aerosol from a painting booth, since the sticky aerosol has a crucial adverse effect on reducing the life of a filter, meaning it cannot perform its functions properly [7,8]. Although a wet removal technique and disposable filters are used to remove sticky aerosol from painting booths, they are not efficient due to the requirement of the secondary removal of wastewater or the frequent replacement of disposable filters. Research into the efficient removal of sticky aerosol from painting booths is required [9,10].

This research agglomerated sticky aerosol with calcium hydroxide in an experimental apparatus imitating an actual painting booth to remove stickiness; collected it on a filter; and studied the cleaning efficiency, total collection efficiency, and fractional collection efficiency of the filter. The intention was to examine the filtration characteristics of the filter in detail and to obtain the optimal operation conditions to apply to actual painting facilities.

2. Material and Methods

2.1. Paint

In this research we conducted the experiment with a painting method generally used in operations for partial painting, such as automobiles, ships, motor bikes, etc. Paint (Scandal Red, Jevisco) and thinner (DR-421W, Noroo paint) were mixed in a 1:1 ratio for the experiment. The paint substances for the experiment were analyzed with GC-MSD (Aglient, Santa Clara, CA, USA), and the analysis results are shown in Table 1, indicating that toluene represents the largest single component.

Table 1. Substance analysis results of paint for the experiment.

Compounds	Mole Fraction
Toluene	0.801
m/p-Xylene	0.042
Butylacetate	0.054
Methyl Ethyl Ketone	0.025
Ethylbenzene	0.065
o-Xylene	0.004
Ethylacetate	0.005
Acetone	0.004

2.2. Calcium Hydroxide

The calcium hydroxide used in this research has been analyzed for its image and substances using a Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) (HITACHI, Tokyo, Japan), as shown in Figures 1 and 2. The substance analysis results show that calcium represents the largest component. Figure 1 shows that the shape of calcium hydroxide that was determined to have agglomeration for the experiment is in a non-spherical form. An SEM image analysis has been carried out, as it has been determined that it is possible to verify the shapes of viscous paint aerosol and calcium hydroxide on agglomerations when collected on a filter.

Figure 1. *Cont.*

Figure 1. 1000 and 10,000 times magnified images of calcium hydroxide.

Figure 2. *Cont.*

Figure 2. Substance analysis results of calcium hydroxide with EDS.

2.3. Filter

The specifications of the filter used in this research are shown in Table 2, and the appearance of its installation is shown in Figure 3. The filtration area of the filter is 8 m², and the total filtration area of 4 filters is 32 m², as used for the experiment.

Figure 3. The scene of a filter installed in an apparatus for the experiment.

Table 2. The specifications of the filter for the experiment.

Parameter	Value
Filtration area	32 m ²
Pleat number	400
Filter media material	Polyester, membrane coating
Filter thickness	550 µm
Quality of the filter media	PTFE(Polytetrafluoroethylene)
Air permeability	7.5 cm ³ /cm ² /s
Cartridge dimension	494 mm × 1050 mm

2.4. Procedure

The experimental conditions to remove the sticky aerosol are summarized in Table 3, and a flow diagram of the experiment and actual laboratory scene is shown in Figure 4. The test equipment includes a painting booth, a spray gun, a coagulant supplier, an air compressor, a control box, and 2 lines of filters installed. The paint was quantitatively sprayed in 10 g/min under 2 kg/cm² of compressed air in the painting booth, and the sticky aerosol is mixed with the calcium hydroxide to lose its stickiness in order to be captured in the filter. As the aerosol captured by the filter increases, the pressure drops over time due to the fluid build-up, with pulsing applied at certain intervals. As there were concerns about a fault of the aerosol spectrometer (GRIMM, Model 1.108), the aerosol was diluted using dilution equipment (Aerosol Diluter, Model DI-120) to 100 times in order to measure the inlet concentration. It was not diluted to measure the concentration at the outlet. In order to measure the pressure drop, pressure drop measurement ports were installed before and after the fluid passed through the filter, using an electronic remote differential pressure sensor (Differential pressure transmitter, Rosemount. Inc., West Florissant Avenue, Shakopee, MN, USA).

(a)

Figure 4. Cont.

(b)

Figure 4. (a) Flow diagram and (b) scene of the actual laboratory.**Table 3.** Summaries of the experimental conditions.

Parameter	Value
Flow rate	5, 10, 15 Nm ³ /min
Number of filter elements	4
Type of filter	Bag filter
Dimension of the filter	Depth: 494 mm Height: 1050 mm Thickness: 100 mm
Pulsing system unit	T-type pulse injector
Cohesive agent type	Calcium hydroxide
Feed rate of calcium hydroxide	10 g/min
Feed rate of paint	10 g/min

3. Results and Discussion

3.1. Theory

A filter basically has a pressure drop due to the flow of fluid. Considering the entire system, the pressure drop of the filter is an important factor, as shown in Equation (1) below [11]:

$$\text{Pressure drop of filter} = (64\mu LU\alpha^{1.5} (1 + 56\alpha^3))/(d_f^2) \quad (1)$$

In Equation (1), μ is the viscosity of air, L is the filter thickness, U is the filtration velocity of the filter, d_f is the fiber diameter, and α is the solidity of the filter.

The total pressure drop of a filter is defined as the summation of the pressure drop of a filter (1) and the pressure drop of an aerosol layer, as shown in Equation (2) [12]:

$$\Delta P = \Delta P_f + \Delta P_a \quad (2)$$

In Equation (2), ΔP is the total pressure drop (mmH₂O), ΔP_f is the pressure drop of a filter (mmH₂O), and ΔP_a is the pressure drop of the aerosol (mmH₂O).

The total collection efficiency is the entire collection efficiency of the aerosol at the outlet per aerosol concentration of the aerosol at the inlet. The total collection efficiency is expressed as Equation (3) [13]:

$$\text{Total collection efficiency} = (C_{in} - C_{out})/C_{in} \times 100\% \quad (3)$$

In Equation (3), C_{in} is the aerosol concentration of the aerosol at the inlet ($\#/cm^3$), and C_{out} is the aerosol concentration of the aerosol at the outlet ($\#/cm^3$).

The efficiency according to the aerosol size of the aerosol refers to the fractional collection efficiency, as shown in Equation (4) [14]:

$$\text{Fractional collection efficiency} = (1 - C_{out}/C_{in}) \times 100\% \quad (4)$$

In Equation (4), C_{in} is the respective aerosol concentration of the aerosol at the inlet ($\#/cm^3$), and C_{out} is the respective aerosol concentration of the aerosol at the outlet ($\#/cm^3$).

3.2. Cleaning Interval

A function of a filter is to collect aerosol between its fibers with mechanisms of inertial collision and direct blocking. Based on Equation (2), as the pressure drop increases due to the aerosol, the aerosol must be twisted with an impacting air flow stuck on the filter, which refers to pulsing. The time between the first pulsing and the second pulsing refers to a cleaning interval [15,16].

Figure 5 shows the results of the cleaning interval at the flow rates 5, 10, and 15 Nm³/min. After 3 times cleaning, the cleaning intervals at the flow rates 5, 10, and 15 Nm³/min are 424, 170, and 105 min, respectively. It has been checked that the lower the flow rate, the longer the cleaning interval.

Figure 5. Cleaning interval results with the flow rate variable.

3.3. Residual Pressure Drop

A pressure drop value measured after the pulsing refers to the residual pressure drop [17]. Figure 6 shows a rapid increase at the flow rate 15 Nm³/min as the cleaning times increase, and the relatively low flow rates 5 and 10 Nm³/min show slowly increasing results. Since a low flow rate has a low residual pressure drop, the aerosol must be removed at the low flow rate, considering operating costs and the efficiency of the equipment.

Figure 6. Residual pressure drop trend with flow rate variable.

3.4. Cleaning Efficiency

The cleaning efficiency can be determined as the aerosol captured on the filter after the cleaning operation. When a large amount of the aerosol has desorbed from a filter, it has a high cleaning efficiency. On the contrary, when a large amount of the aerosol remains on the filter after the dedusting operation, its cleaning efficiency is defined as low [18,19]. Figure 7 shows that the average cleaning efficiencies at the flow rates 5, 10, and 15 Nm³/min are 99.18, 95.21, and 89.9%, indicating that the higher the flow rate, the lower the cleaning efficiency.

Figure 7. Cleaning efficiency results with flow rate variable.

3.5. Collection Efficiency

For research on the removal of air pollutants, the concentration of incoming and outgoing aerosol is the most important factor. The results of the total collection efficiency to determine the aerosol

removing efficiency with the total aerosol concentration, and of the fractional collection efficiency to determine it with the aerosol size are important [20,21]. This research has measured the aerosol concentration in a range of aerosol sizes from 0.3 to 20 μm . Figure 8 shows the total collection efficiency, indicating 99.41, 90.98, and 83.37% at the flow rates 5, 10, and 15 Nm^3/min . Figure 9 shows the collection efficiency per aerosol size, indicating a low collection efficiency for aerosol sizes from 0.3 to 2 μm at the flow rate 15 Nm^3/min used in this experiment. There is a similar collection efficiency with aerosol sizes from 2 to 20 μm at the flow rates 10 and 15 Nm^3/min . The features to remove aerosol have been examined at the flow rates 5, 10, and 15 Nm^3/min . It was impossible to carry out the experiment under the flow rate 5 Nm^3/min due to the precipitation of aerosol, and difficult to find out result trends for over 15 Nm^3/min . As a result, it was possible to get clear result trends for the experiment at 5 units of flow rate conditions.

Figure 8. Total collection efficiency results with flow rate variable.

Figure 9. Fractional collection efficiency results with flow rate variable.

3.6. Image Analysis

The photos of the filter used in this research before and after the experiment are shown in Figure 10. For a correct image analysis, the images before and after the experiment with SEM are shown in Figure 11. From a 1000 times magnification with SEM, we have checked that the aerosol is captured between the fibers of the filter after the experiment.

Figure 10. Photos of filters (a) before and (b) after the experiment.

(a)

Figure 11. *Cont.*

(b)

Figure 11. 1000 times magnified photos of filter media (a) before and (b) after the experiment.

4. Conclusions

This research has imitated an actual painting facility for removing sticky aerosol and conducted an experiment applicable to industrial settings. The sticky aerosol has been agglomerated with calcium hydroxide to lose stickiness, collected by a filter and collected in a hopper. The experiment has been carried out with variable flow rates of 5, 10, and 15 Nm³/min, showing the following trend: the lower the flow rate, the longer the cleaning interval. The residual pressure drop is low, while the cleaning efficiency is high. The total and fractional collection efficiency with aerosol sizes from 0.3 to 20 µm showed high values at low flow rates. From the observation of images of the filter before and after the experiment, we checked that the aerosol is well captured. However, at flow rates that were lower than the experimental conditions, the aerosol sank, making the experiment impossible. Based on the results of this research, we confirm that this research is applicable for operations that generate sticky aerosol.

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