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Short Communication

Efficient wet-dust collection system using foam

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ABSTRACT

A wet-dust collection system that uses foam rather than liquid droplets was developed to remove environmental pollutants from gases emitted from stationary sources. Operational conditions for the formation of a stable foam layer in the dust collector were identified. Over 99.9% of gas containing test powder could be removed when the gas was passed through the system. In absorption experiments on gaseous SO_2 with H_2O_2 as the reactive absorbent, an absorption rate of >99.1% was obtained using the proposed system. Furthermore, in the absence of H_2O_2 and using a surfactant solution instead of only water, a higher absorption rate of SO_2 was achieved with the formation of a foam layer.

KEYWORDS: wet-dust collection system, foam, environmental pollutant.

INTRODUCTION

Pollutants such as soot, dust, SOx, NOx, and volatile organic compounds (VOCs) are found in gases emitted from factories and industrial facilities. The formation of suspended particulate matter, acid rain, and photochemical oxidants can be attributed to these environmental pollutants. Therefore, a crucial challenge lies in addressing both particulate and gaseous environmental pollutants present in the gases emitted from stationary sources. Wet-dust collection systems demonstrate excellent performance in removing these pollutants and are thus widely used. Conventional wet-dust collection systems mostly operate by generating a considerable amount of small liquid droplets to enhance the spatial density of droplets in the airflow, thereby removing particulate pollutants [1-5]. Consequently, an increased liquid consumption and high pressure losses are observed when capturing small particulate matter. Additionally, a costly problem arises in the treatment of large volumes of wastewater when absorption liquids are used for the efficient removal of gaseous pollutants.

Instead of liquid droplets, the use of foam as the medium for pollutant removal was considered. Foam layers possess a low liquid content per volume (<15%) [6], resulting in a large contact area between the gas and liquid per volume. Additionally, foam flow in the device encounters low pressure losses. Furthermore, high gas absorption performance in gradually rising foam layers has been reported in a previous study [7]. The use of foam in the wet-dust collection system facilitates the simultaneous removal of particulate and gaseous pollutants with minimal liquid consumption and low pressure losses. In this study, a wet-dust collection system using foam was developed and its performance in removing particulate matter from gases and absorbing gaseous substances was evaluated.

MATERIALS AND METHODS

Apparatus

Figure 1 shows a schematic of the wet-dust collection system using foam. The dust collector

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had a column with an inner diameter of 9 cm and a height of 55 cm. A perforated plate (hole size of 1 mm, open area ratio of 4%) facilitated gas dispersion into the liquid *via* a gas chamber at the bottom of the column. Triton X-100, which is a nonionic surfactant, was used as the foaming agent. A foam-breaking impeller comprising a six-bladed vaned disk with a diameter of 6 cm was installed at the top of the column.

Removal of particulate matter

Test powder 1 [8] designated by JIS Z 8901 was used for particulate matter. The gas superficial velocity ranged from 0.8 to 1.5 cm/s, and the liquid height in the dust collector varied from 3.5 to 8.8 cm. Diluted solutions of the surfactant were used in the range of 0.05-0.15 g/l. The solid lines in Figure 1 indicate the introduction of gas into the dust collector from the air compressor. A fluid bed-type fine particle disperser filled with glass beads was used to facilitate particulate matter dispersion in dry air, which was then supplied to the dust collector as the treated gas. A particle counter (HHPC2+; Beckman Coulter Inc.) was used to evaluate the concentration of particulate matter in the gas, assessing the number of particles larger than 5 μm in volume-equivalent gas. The treated gas was then introduced into the dust collector with a foam layer, and the particle concentrations at the inlet (N_{in}) and the outlet (N_{out}) were measured. The particle removal efficiency (P) was then calculated by the formula $P = (N_{in} - N_{out}) / N_{in} \times 100$.

Absorption of gaseous substances

SO_2 gas was used as a gaseous substance. The dashed lines in Figure 1 indicate the introduction of the mixed gas into the dust collector from the air compressor and gas cylinder. Dry air was mixed with SO_2 gas and then supplied to the dust collector as the treated gas. The flow rates of dry air and SO_2 gas were adjusted using mass flow meters. The gas sparge rate of the treated gas was 3.8 l/min, which corresponds to a gas superficial velocity of 1.0 cm/s. The concentration of SO_2 in the treated gas ranged from 20 vol ppm to 430 vol ppm. The liquid was a diluted solution of 0.1 g/l surfactant. H_2O_2 was used as a reactive absorbent. The liquid height in the dust collector was set to 5 cm. Gas sampling and SO_2 analysis in the gas

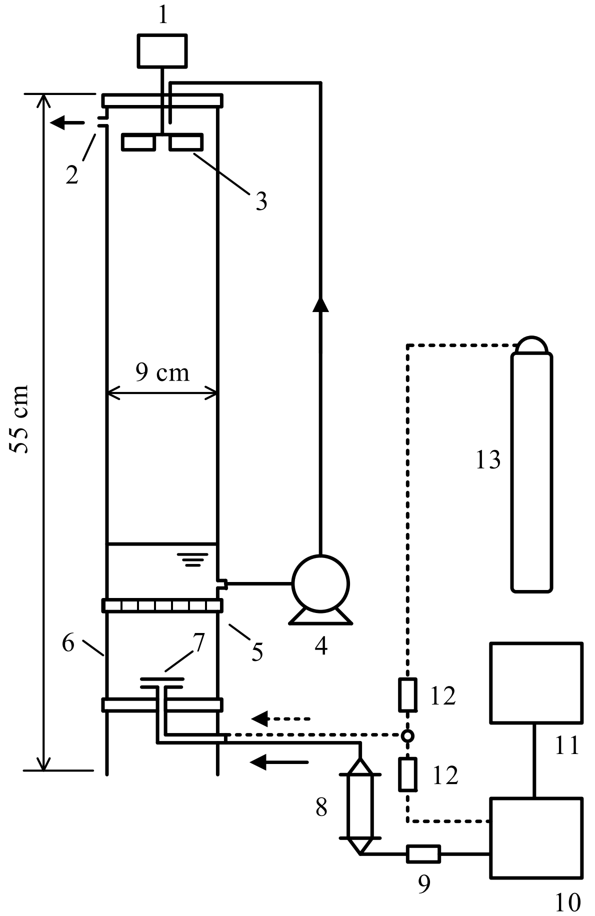

Figure 1. Schematic of experimental apparatus: (1) motor, (2) gas outlet, (3) foam-breaking impeller, (4) pump, (5) perforated plate, (6) gas chamber, (7) gas sparger, (8) fluidized bed-type fine particle disperser, (9) volumetric flow meter, (10) air dryer, (11) air compressor, (12) mass flow meter, and (13) standard SO_2 gas cylinder.

followed the analysis method of sulfur oxides in exhaust gases [9]. The inlet SO_2 concentration (C_{in}) and outlet SO_2 concentration (C_{out}) were determined by measuring the SO_2 concentration in the gas using ion chromatography. The SO_2 absorption rate (S) was then calculated using the formula $S = (C_{in} - C_{out}) / C_{in} \times 100$.

RESULTS AND DISCUSSION

Development of the wet-dust collection system using foam

Liquid and foam layers are placed between the perforated plate and the foam-breaking impeller in the dust collector. The working liquid volume must be small; in other words, the liquid height must be low and the foam layer height must be high. Additionally, the formation of a stable foam layer is essential to the removal of particulate matter and gaseous substances using foam. The surfactant concentration and the gas superficial velocity influence the strength of foam generation. Therefore, the formation of a foam layer in the dust collector was investigated by varying the gas superficial velocity, surfactant concentration, and liquid height. However, despite an increased surfactant concentration or gas superficial velocity, foaming weakened over time and a stable foam layer could not be formed. This phenomenon is attributed to the surfactant concentration in the foam layer, which results in less surfactant in the liquid. Therefore, a constant amount of liquid (0.33 l/min) was supplied to the upper surface of the rotating foam-breaking impeller (Figure 1). This set-up resulted in a liquid flow returning from the foam layer to the liquid section, facilitating the formation of a stable foam layer that remained consistent over time. Furthermore, the necessary conditions for foam layer formation in this dust collector include gas superficial velocities of ≥0.8 cm/s, surfactant concentrations of ≥0.05 g/l, and liquid heights of ≥3.5 cm.

Removal of particulate matter in the wet-dust collection system using foam

Figure 2 shows the results of particle removal efficiency when the gas superficial velocity was varied under the conditions of a liquid height of 5 cm and a surfactant concentration of 0.1 g/l. A slight decrease in particle removal efficiency was observed as the gas superficial velocity increased, but over 99.9% of particulate matter was removed. Furthermore, the particle removal efficiency remained above 99.9% when the liquid height and surfactant concentration were varied. The passage of gas through the liquid as bubbles facilitates the formation of foam on the liquid surface. A particle removal efficiency of 99.8% was obtained based on experimental results using water as the liquid under the conditions of a liquid height of 5 cm and a gas superficial velocity of 1.0 cm/s. This finding indicates that despite low liquid height, most particulate matter is removed when passing through the liquid as bubbles.

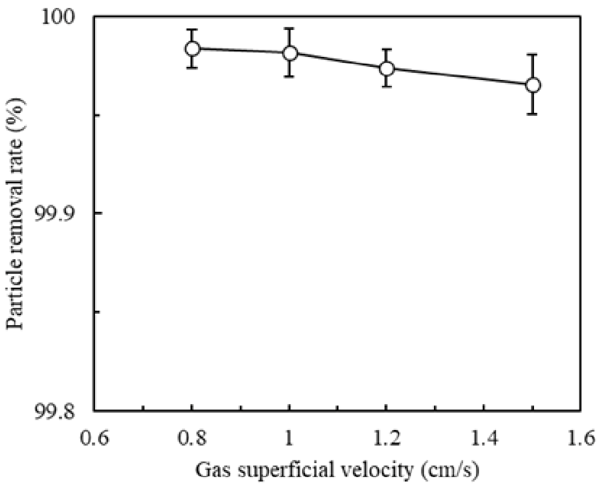

Figure 2. Effects of gas superficial velocity on particle removal rate.

Absorption of gaseous substances in the wet-dust collector system using foam

In conventional wet-dust collectors, H_2O_2 solution is commonly used as an absorption liquid to remove SO_2 from gases emitted from stationary sources. Therefore, the SO_2 absorption performance of this dust collector system was investigated by adding H_2O_2 (0.3 w/v%) to a surfactant solution. The SO_2 absorption rates remained >99.1% despite variations in SO_2 concentrations in the treated gas. Then, the SO_2 absorption performance of this dust collector system without additional H_2O_2 was examined. Foam layers are absent when water is used as the liquid. The comparison of SO_2 absorption rates under conditions with and without a foam layer at the same liquid height of 5 cm is presented in Figure 3. In both conditions, the SO_2 absorption rate tends to decrease as the SO_2 concentration increases. Furthermore, the presence of a foam layer resulted in higher SO_2 absorption rates compared with conditions without a foam layer. The increase in the absorption rate is believed to be attributed to the increased contact area and contact time between the gas and liquid due to the presence of the foam layer. Under conditions where the SO_2 concentration in the treated gas was 100 vol ppm or less, an absorption rate of

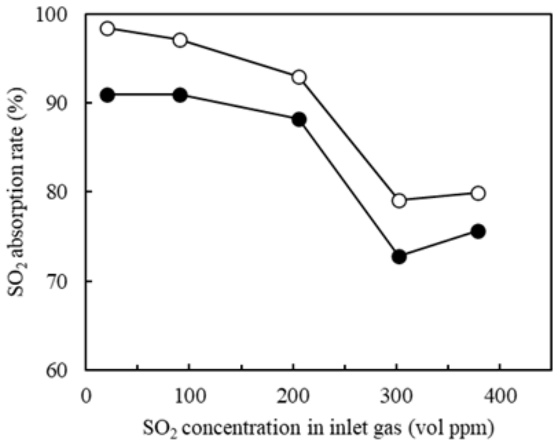

Figure 3. Comparison of SO_2 absorption rate under conditions with and without a foam layer: (○) with a foam layer and (●) without a foam layer.

≥97.0% was achieved, demonstrating the superiority of this wet-dust collector system under conditions without additional reactive absorbent.

CONCLUSIONS

Overall, in the wet-dust collection system using foam, supplying liquid inside the dust collector above the foam layer is necessary for the stable formation of the foam layer. The particle removal efficiency in the dust collector was over 99.9% within the range of gas superficial velocities of 0.8-1.5 cm/s. The addition of H_2O_2 to the surfactant solution as a reactive absorbent yielded over 99.1% SO_2 absorption rates in the treated gas, with SO_2 concentrations ranging from 20 to 430 vol ppm. Additionally, under conditions without H_2O_2, higher SO_2 absorption rates were observed in the presence of a foam layer using a surfactant solution than in conditions where no foam layer was present, and water alone was used.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest related to the content or composition of this article.

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