Removal of Fine Powders from Film Surface. II. Effect of Operating Parameters on the Removal Efficiency

Satoru WATANO,*,[a] Takumi OKAMOTO,[a] and Teruo SUZUKI[b]

[a] *Department of Chemical Engineering, Osaka Prefecture University; 1–1 Gakuen-cho, Sakai, Osaka 599–8531, Japan: and* [b] *Kasuga Denki Co. Ltd.; 2–16–18 Higashi-kamata, Ohta-ku, Tokyo 144–0031, Japan.*
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In the previous paper, a novel fine particle removal system composed of a corona-discharge neutralizer, a pulse-jet air unit and an image processing system has been developed and applied to the removal of fine particles from film surface. We have calculated the van der Waals and electrostatic forces between particle and film and then reported that the electrostatic force influenced the adhesion characteristics significantly and thus the elimination of electrostatic charge should be necessary for the effective removal of fine particles. In this paper, we have modified the corona-discharge neutralizer for getting much better removal performance. The effect of operating parameters on the removal efficiency was investigated experimentally. The ratio of fine particle remained on the film surface after removal experiment as a function of particle size was measured. It was found that fine particles smaller than 15 μm, which were impossible to remove by other conventional techniques, could be almost completely removed. This method is anticipated to be used in the capsule filling, film packaging and tabletting processes for prevention of stain on lens of video automatic inspection machines, unpredictable movement of electronic devices, and deteriorates of product quality.

Key words removal; fine particle; film surface; electrostatic force; neutralizer removal efficiency

In the capsule filling, film packaging and tabletting processes, sticking of fine particles onto the product surfaces occurs due to the electrostatic charge. This may cause stain on lens of video automatic inspection machines, unpredictable movement of electronic devices, and deteriorates of product quality. In order to prevent these problems, removal of fine particles from product surface is required.

In our previous paper,[1] we have developed a fine particle removal system composed of a corona-discharge neutralizer, a pulse-jet air unit and an image processing system, and then applied to the removal of fine particles from film surface. It was found that the electrostatic force was significantly large as compared to the van der Waals force and should be removed for better removal of fine particles. In practice, the removal efficiency was still 80% even though eliminating the electrostatic charge. It was because the week ion generation rate of the previous corona-discharge neutralizer. For complete removal of fine particles from film surface, much larger ion generation rate is required.

In this study, we have modified the previous corona-discharge neutralizer for better ion generation rate. The effect of operating parameters such as airflow pressure, spray distance and angle of spray on the removal efficiency was investigated. The ratio of fine particles remained on the film as a function of particle size was also investigated.

Experimental

Cornstarch particles (Cornstarch W, Nippon Shokuhin Kako Co. Ltd., Japan) having their median diameter were 15 μm was used for powder sample. A gelatin film (Shionogi Qualicaps, Co., Ltd., Japan) widely used for a conventional gelatin capsule was adopted for the film material. Prior to the experiments, cornstarch particles and the film were dried in a shelf drier under the conditions of 323K and 24 h, in the same way as previously reported.[1]

Figure 1 illustrates an experimental apparatus and a modified corona discharge neutralizer. The previous neutralizer utilized commercial 100 V AC power supplies,[1] while this one uses high voltage AC power supplies. To increase the ion generation rate, the distance between the needle electrode and outside metal case is made short.

The fine particle removal experiment was conducted in the same way as previously reported.[1] A gelatin film (25×25 mm) was placed flat onto a x-y stage, and then approximately 300 particles were dropped inside a circle of 10 mm diameter on the film through a vibrated wire mesh having 38 μm (280 mesh) opening. The fine particles were removed by a newly developed neutralizer and then the number of fine particles remaining inside the circle was measured by using an image processing system.[2] The size distribution of the remaining particles and the number base removal efficiency were calculated *via* a personal computer. The operating conditions for the fine particle removal experiments are listed in Table 1. In this experiment, number of pulses was set at one (single shot), although it was four in the previous paper.[1] This was because i) the newly developed neutralizer was strong

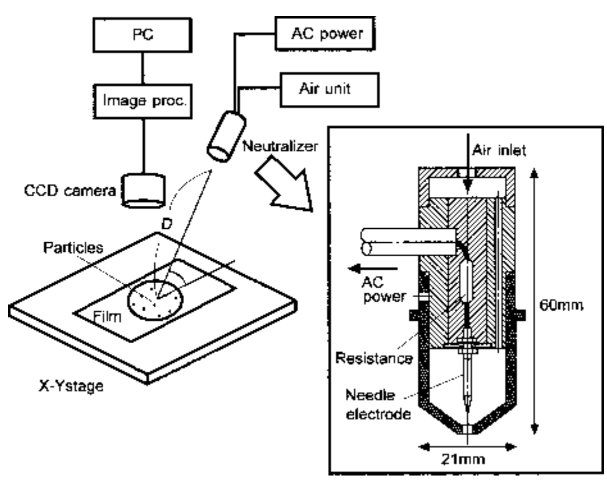

Fig. 1. Schematic Diagram of Experimental Apparatus and Newly Developed Neutralizer

Table 1. Operating Conditions

Number of particles	300
Distance between nozzle and film, *D*	10—30 mm
Number of pulses	1
Air (jet) pressure	0.1—0.3 MPa
Duration of air jet	0.5 s
Jet interval	0.5 s
Jet spray angle, θ	0—90 deg

* To whom correspondence should be addressed. e-mail: watano@chemeng.osakafu-u.ac.jp
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enough to remove fine powders with a single shot, and ii) considering the continuous operation, four times air shots were inconvenient.

The ion generation rate of the neutralizer was measured by using a faraday cage.[3,4] The faraday cage was made of double metal cylinders, both of which were insulted by a Teflon resin. The ion was lunched directly through the neutralizer into the inside cylinder, and then the voltage between the inside and outside cylinder was measured. By multiplying the voltage with the electrostatic capacity of the faraday cage, the electric charge of generated ion was obtained. The ion generation rate was finally defined as the electric charge by unit time.

Results and Discussion

Measurement of Ion Generation Rate Figure 2 compares the ion generation rate of the newly developed corona discharge neutralizer with that of the previous one. The ion generation rates of both neutralizers increased with the supplied air pressure. This was because the neutralizer ionized much larger amount of air molecules if the supplied air was large. Also, due to the modification with high voltage power supply, the newly developed neutralizer could generate ion approximately 100 times as much as that of the previous one.

Performance of Particle Removal Efficiency Figures 3 and 4 indicate particle removal efficiency as a function of supply voltage under various air pressures and distances between film and neutralizer. In any distances, the removal efficiency increased with the supply voltage. It was because the neutralizer could generate much larger amount of ion if the supply voltage was large. However the efficiency in case of high voltage larger than 3 kV indicated almost the same value. The capacity which corona discharge could generate ion reached to the upper limit. Also, the shorter distance revealed larger removal efficiency. As was clear from the removal efficiency of air only (0 V), the air could blow away much greater number of fine particles if the spray distance became short. Also, the ratio of ion that extinct while it went from the neutralizer to the film decreased, leading to increase the removal efficiency. As compared the both figures, the tendency of the removal efficiency of different air pressures was almost the same. However, as shown in Fig. 2, the large air pressure could generate much larger amount of ion, resulting in the larger removal efficiency.

Considering the ion generation performance and the particle removal efficiency under various operating conditions, 3 kV and 0.2 MPa with the shortest distance should be the optimum conditions. However, the shortest distance of 10 mm sometimes caused peeling of the film from the bottom x-y stage due to the large air pressure. The distance of 20 mm should be the appropriate value for the particle removal system. In the following the removal tests will be conducted under the optimum conditions of 3 kV and 0.2 MPa with 20 mm distance.

Figure 5 investigates the effect of spray angle on the removal efficiency. The best removal efficiency was obtained when the spray angle was smaller than 30 deg (spray angle 0 meant the angle between neutralizer and film was 0, while 90 deg showed the neutralizer was located perpendicular to the film surface). If the spray angle was larger than that, the efficiency decreased with the angle. This was because the component of pressure in the direction of perpendicularly downward increased, leading to press down the particles not to be removed easily.

Figure 6 compares particle size distribution before and after the particle removal experiments. The original size dis-

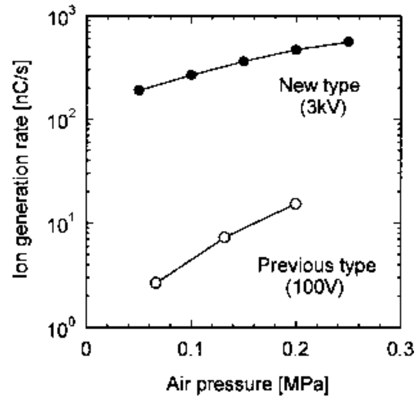

Fig. 2. Ion Generation Behaviors

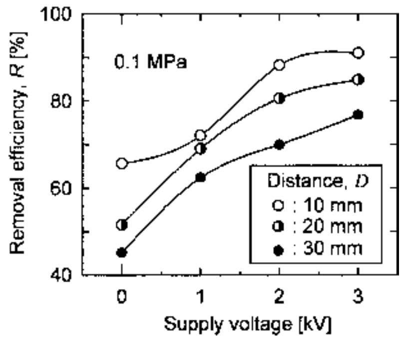

Fig. 3. Particle Removal Efficiency
P=0.1 MPa, θ=30 deg.

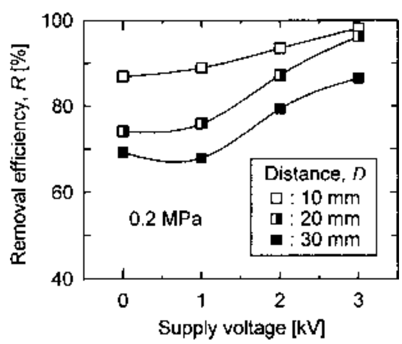

Fig. 4. Particle Removal Efficiency
P=0.2 MPa, θ=30 deg.

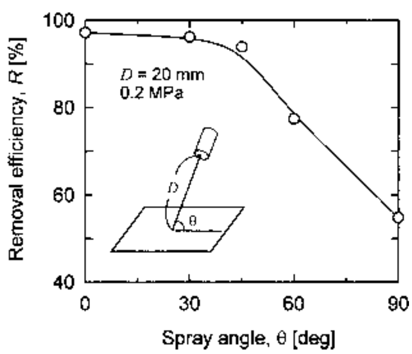

Fig. 5. Particle Removal Efficiency as a Function of Spray Angle

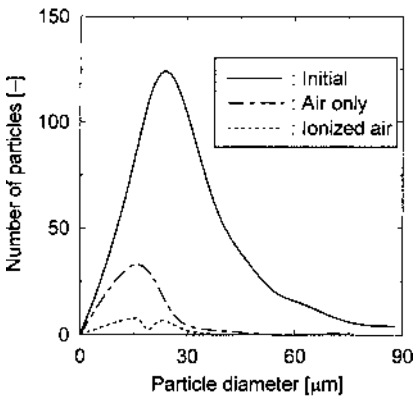

Fig. 6. Particle Size Distribution before and after the Removal Experiment

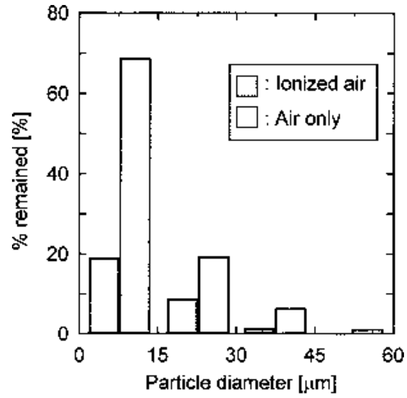

Fig. 7. Ratio of Particle Remained as a Function of Particle Size

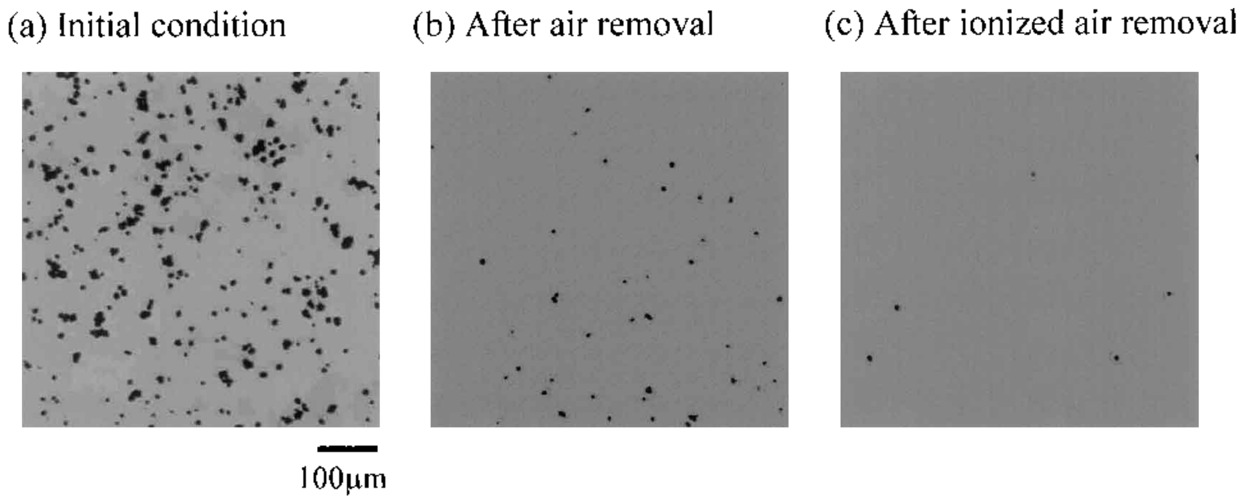

Fig. 8. Photographs of Particle Remaining Behaviors

tribution was shown in the same figures for the control. Figure 7 investigates the effect of particle diameter on the ratio of particles remained on the film surface when the air and ionized air was used. Figure 8 shows photographs of particles onto the film surface before and after the removal experiments.

Seen from these figures, the effect of ionized air was obvious; large number of small particles still remained on the surface without the ion. Especially, most of the particles smaller than 15 μm remained on the film surface due to the strong electrostatic forces.[1] However, the ionized air could almost remove even such small particles. Photographs shown in Fig. 8 clearly confirm the difference between with and without the use of neutralizer.

As a result, the effects of operating parameters on the particle removal efficiency could be analyzed. It could be said that the ionized air generated by the newly developed neutralizer was very effective to remove small particles, which were impossible by other conventional techniques.[5]

Conclusions

A novel fine particle removal system composed of a corona-discharge neutralizer, a pulse-jet air unit and an image processing system has been developed and applied to the removal of fine particles from film. The effects of operating parameters on the removal efficiency were investigated experimental and the optimum operating conditions were determined. It was found that the ionized air generated by the neutralizer could eliminate the large electrostatic force between particles and film, which enabled the effective removal of fine particles. By using the developed system, the fine particles smaller than 15 μm, which were impossible by other conventional techniques, could be almost completely removed.

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