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Emission of Submicron Aerosol Particles in Operating a Laser Beam Printer

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Laser beam printers can be substantial sources of submicron particles in the indoor environment. The present work investigated particle emissions from a commercial laser beam printer (LBP), which was one of single component, non-magnetic, non-contact mode type LBPs, in various operating conditions. Size distribution and number concentration of particles were measured by a scanning mobility particle sizer (SMPS). The size distribution of particles generated from the printer was 20-200 nm in equivalent mobility diameter, regardless of the operating condition. When the fuser system was operated by fuser controller without development and the temperature of the heating roller was 190°C, particles were detected and their peak concentration was about 10^3 particles/cm^3. Zero percent coverage white papers and five percent coverage black papers, were used, the peak concentrations were 1.5×10^5 particles/cm^3 and 3.3×10^5 particles/cm^3, respectively. These results suggest that the sources of submicron particle generation were rubber of heating roller, paper, and toner.

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1. Introduction

Laser beam printers (LBPs) have come into wide use not only in offices but also in home use due to improvement of an image quality and printing speed from several years ago. LBP has six steps, which are charging, exposure, development, transfer, fusing, cleaning and discharge, for the printing product. In these steps, we focused on development and fixing steps for the source of submicron aerosol particles. The mechanism in the development system of a LBP is described in Fig. 1. OPC (Organic Photo-conductive) Drum receives a uniform surface charge in the charging steps. A latent image is created by illuminating the OPC with a light source such as a laser. The OPC becomes conductive in the illuminated areas and the surface charge flows to ground. The latent image is rendered visible by development with a toner particle (charged particles with a typical diameter of the order of 6-8 μm in diameter). The toner image is electrostatically transferred from the developing roller to OPC drum. The mechanism in the fuser system of LBP is described in Fig. 2. The unfused print is passed between a heating roller with a thin rubber coating and a deformable backup roller. The heating roller consists of an aluminum cylinder and a heating coil located near the center. As the paper with toner particles of styrene-acryl ate copolymer, one of the thermoplastic polymer, enters the fusing zone, the heating roller provides thermal energy to the toner particles onto the paper.[1] The soft rubber coating in the deformable backup roller produces a fusing zone, under the force of engagement, of sufficient width to provide enough time and pressure to allow the toner particles to flow together onto the paper.[2] An indoor source of submicron particles lately coming to

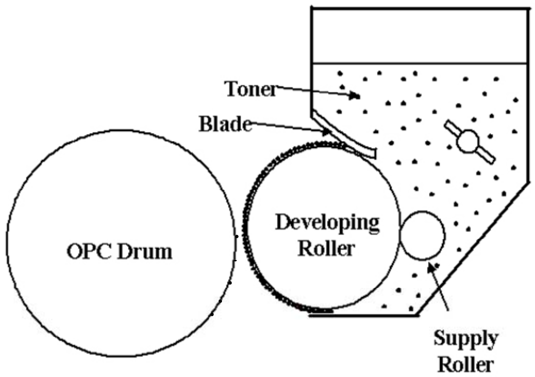

Fig. 1 Development mechanism in the developing system

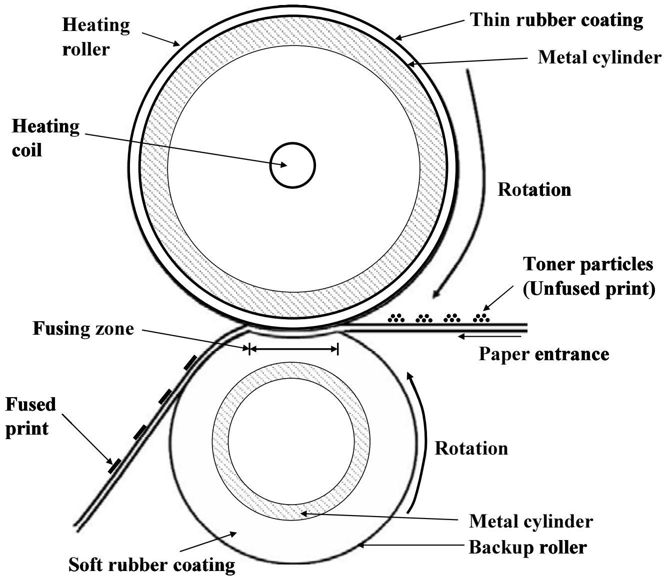

Fig. 2 Fusing mechanism in the fuser system

attention is laser beam printers for home or office use.[3,4] Laser beam printers (LBP) release not only volatile organic compounds (VOC), but can also generate a considerable amount of submicron particles during the printing process.[5] The emission of particles from a LBP depends on variable parameters including type of printer, cartridge, paper, and toner.

Several studies on the emission of submicron particles in a LBP have been carried out. Uhde et al.[6] and Lee and Hsu[7] reported that LBP emitted the VOC and submicron particles. Ewers and Nowak[1] monitored particles and VOC generated in a LBP and reported that the main source of emissions might be a fuser system in the LBP. He et al.[3] monitored submicron particle number concentration in a large open-plan office to assess the potential impact of indoor activities on indoor particle concentrations and measured concentrations of submicron particles in the immediate vicinity of operating printers in a multilevel office building. Schripp et al.[8] reported that the time-dependent characterization of particle release from laser beam printers is of high interest in order to evaluate the exposure of office workers to such emissions. Singh et al.[9] showed distinct emission characteristics associated with warm up and printing cycles. Wensing et al.[10] mentioned that the high-temperature fuser unit is assumed to be one source for ultra-fine particle emission.

Sampling ports of previous works were located near the wall of the chamber or at the exit of the chamber where a laser beam printer was inside. In this paper, we inserted our sampling port right at the backside of the LBP to find the source of submicron aerosol in operating a laser beam printer. If we had located the sampling port near the wall of the chamber or at the exit of the chamber, we might have measured particles already emitted from the printer, agglomerated, and aged, as well as newly-borne particles directly transported from the LBP. We carried out experiments for various operating conditions controlled by a user-defined program, with which we could handle on/off mode of development, fusing step, and control of the temperature of fusing part.

2. Experiments

Our experimental setup is shown in Fig. 3. A commercial LBP, which is one of single component, non-magnetic, non-contact mode type LBPs (Samsung), was placed in a test chamber of 1 m^3 in volume. The back cover of the LBP was opened for measuring particles emitting from the fuser system. A chamber was designed using the acrylic and thickness of 10 mm. Compressed air was delivered to the top of the test chamber, after oil droplets, moisture and contamination particles in the compressed air were removed by a clean air supply, which consisted of an oil trap, diffusion drier, and high efficiency particulate air (HEPA) filter. The air was exhausted from the bottom of the test chamber with the flow rate of 80 L/min (air exchange rate: 4.8 /hr). The sampling point was located near the backside of the LBP which distance from the LBP to sampling port was 1 cm.

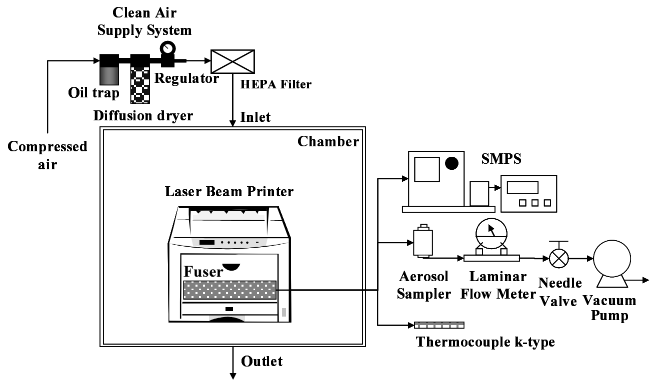

Fig. 3 Experimental setup

The size distribution of sampled particles was measured by a scanning mobility particle sizer (SMPS) system consisting of an electrostatic classifier (TSI 3081), a condensation particle counter (TSI 3025), and an aerosol charge neutralizer. The SMPS system was operated with a sample flow of 0.3 L/min, a sheath flow of 3 L/min, and a scan time of 4 minutes. Using the SMPS, the number concentration of particles at 17-723 nm in mobility equivalent diameter was measured. The mobility equivalent diameter defined as a spherical particle which equal to particle volume equivalent diameter.

First, measurements were performed when the fuser system was operated by a user-defined program which controlled the temperature of the heating roller without development. Temperature of the heating roller was measured using a k-type thermocouple. Particle size distributions were measured when the temperature was 100°C, 150°C, or 190°C. Then, particle concentrations and size distributions were measured for the time-dependent emission when normal white papers (surface coverage 0%), and papers of 5% black were used instead of operating the user-defined program. Experiments for each condition were repeated 3 times. In Fig. 4-6, average values are plotted. The geometric standard deviations ranged between 1.499 and 1.917. For SEM analysis, particles were also sampled by using an aerosol sampler.[11] This aerosol sampler collected particles by the combination of electric field, impaction of particles, and brownian diffusion.

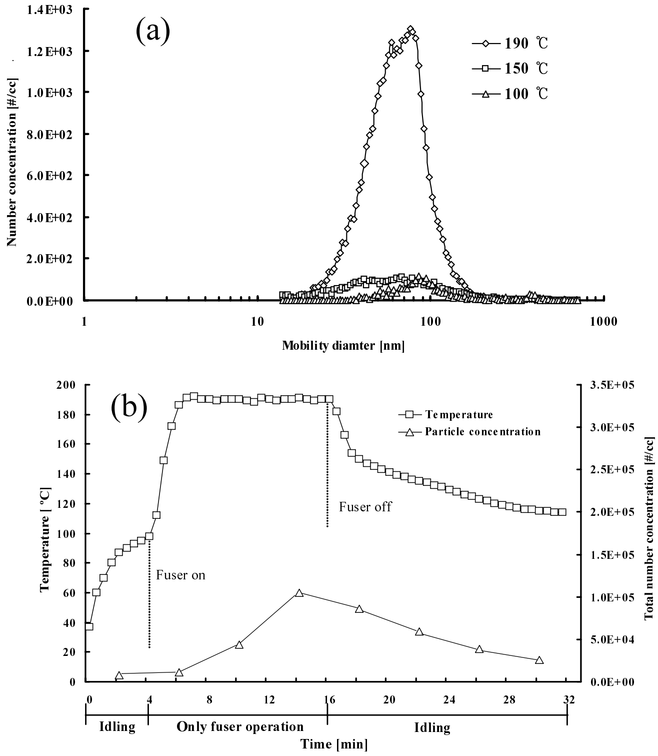

Fig. 4 Data for only fuser operation (a) Particle size distribution with variation of heating roller temperature (b) Particle number concentration with sampling time

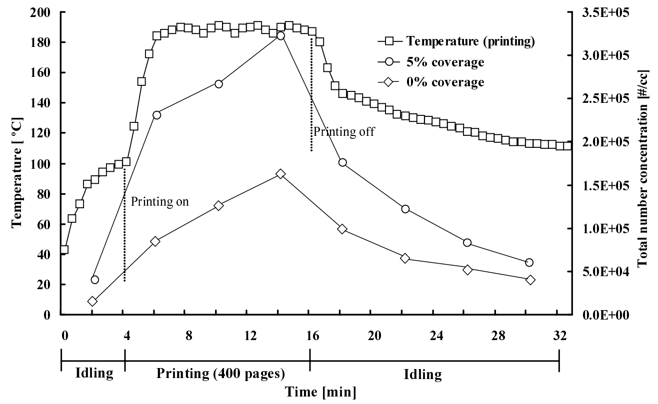

Fig. 5 Particle number concentrations with sampling time for papers of different toner coverage

3. Results and Discussions

The particle size distribution in the operation of fuser system is shown in Fig. 4(a). It was interesting that particle of about 20-200 nm in diameter were detected when the temperature of the heating roller was 190°C, even though no papers were used. However, when the temperature was 100°C or 150°C, much less particles were detected. The temperature of 190°C was selected since it is the temperature of the heating roller for normal printing mode of a LBP. Figure 4(b) shows particle concentrations with variation of printer operation. The printer was idling for initial 4 minutes. During this period, the temperature of heating roller was increased due to

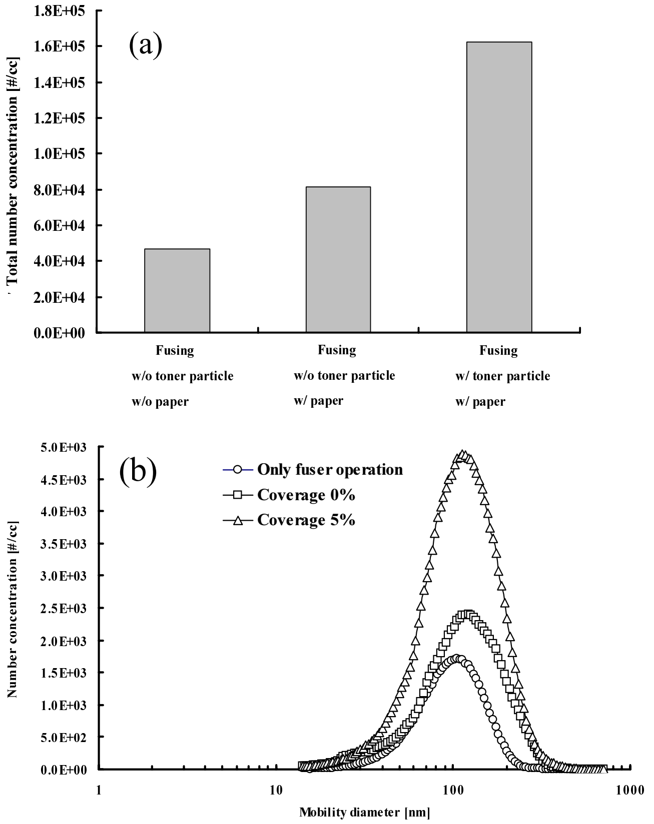

Fig. 6 Averaged data during 32 min. (a) Total number concentration. (b) Particle size distribution

constant joule heating. Then, the fuser system was on and the temperature of heating roller was set to 190°C. The temperature increased drastically and became steady state at 190°C. The temperature started decreasing when the fuser system was off for another idling mode.

The particle data show that particles were detected even during the idling mode of the printer. When the fuser system was on, the particle concentration was increasing. Since the results were obtained without using any papers and the particle concentration strongly depended on temperature, one of possible particle sources was plastic part, like rubber, of heating roller in the fuser system. Experiments were carried out with normal printing of papers. The concentration increased as % coverage increased. When papers of 5% black were used, the particle concentration increased substantially to 3.3×10^5 particles/cm^3. Even after the printing was finished and the printer was in idling mode, quite a large amount of particles were still detected. It was confirmed that toner particles and papers themselves were potential sources of particle emission in a LBP.

Figure 6 shows time averaged total number concentration and size distribution during 32 minutes. These results show that the amount of particles emitted from the printing with 0% coverage white papers was higher than in only fuser operating but lower than in the printing with 5% coverage black papers. These results suggest that the sources of submicron particle generation were rubber of heating roller, paper, and toner. It was interesting that the particles sizes were almost independent of operating condition.

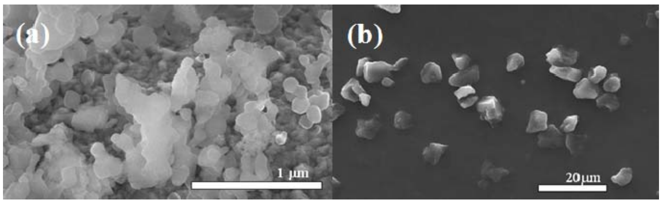

Fig. 7 SEM images (a) emitted particles (b) toner particles

Figure 7 shows the SEM images of (a) emitted particles and (b) toner particles from LBP using the aerosol sampler. As shown in Fig. 7(b), the toner particles in the LBP had no round shapes because the particles were obtained by pulverization process. The toner particles consisted of 80-90% of polyester based resin particles whose mean sizes were 6-8 μm in diameter (primary particles) and 10-20% of pigment, charge control agent, and other outer additive particles which were attached to the primary particles (secondary particles; 10-100 nm in diameter). The toner particles in Fig. 7(b) shows mean size around 6-8 μm and are separated from each other. But emitted particles have round shapes and coagulated each other as shown in Fig. 7(a). It shows that the particles emissions of LBP were caused by the secondary formation of components in the heating and backup roller of fuser system[12] as well as by directly from paper and toner.

4. Conclusions

We intended to find the source of submicron aerosol in operating a laser beam printer with a user-defined program. The size distribution of particles generated from the printer was 20-200 nm in equivalent mobility diameter, regardless of the operating condition. The result did not consider particle dynamics occurring in the chamber. The particle growth by coagulation could be very fast, as well as the losses to the walls, so the particle concentration measured would not the same as what is emitted by the printer because the time resolution of the SMPS (4 minutes). Despite this limitation, the particles sizes were almost independent of operating condition. When the fuser system was operated by the fuser controller without development and the temperature of the heating roller was 190°C, particles were detected and their peak concentration was about 10^3 particles/cm^3. Zero percent coverage white papers and five percent coverage black papers, were used, the peak concentrations were 1.5×10^5 particles/cm^3 and 3.3×10^5 particles/cm^3, respectively. These results suggest that the sources of submicron particle generation were rubber of heating roller, paper, and toner.

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