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Assessment of the Charged Aerosol Value in Copy Centers

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Abstract: This study was performed to examine the potential health effects of copiers on their users and relevant workers by evaluating the charged aerosol current generation characteristics and indoor air quality (IAQ) in the copy center. In the 10 copy centers and one control site that were investigated in this study, the charged aerosol generation characteristics (effective levels, charged aerosol current, and charged aerosol concentration) and air pollutants (fine particles, ozone, and nitrogen oxide) were measured indoors and outdoors, and compared. In addition, a six-day continuous measurement was performed in a copy center to assess the charged aerosol generation characteristics according to the copying volume and the copier operation, and their correlation with indoor air pollutants. The indoor and outdoor charged aerosol effective levels in the 10 copy centers were 93.4% and 82.4%, respectively, and they were about 1.4 times higher than the charged aerosol effective level in the indoor control site (66.2%). The comparison of the negative and positive ion currents by space showed that the positive ion current was about 4.2 times higher indoors than outdoors, and about 2.5 times higher during the operation time than during the non-operation time. The indoor charged aerosol concentration (1,512.3 ions/cm^3) was about 4.6 times higher than the outdoor concentration (325.8 ions/cm^3), and 19.5 times higher than the indoor charged aerosol concentration in the control site (77.3 ions/cm^3). Based on these results, it was found that the operation of the copier was an important influential factor of the charged aerosol generation level in the copy center, and that the positive ions were dominant. In the analysis of the correlation between the indoor charged aerosol generation and the air pollutants, the effective level had high positive correlations with the charged aerosol concentration (r=0.938, p<0.01) and O_3 (r=0.870, p<0.05). The charged aerosol concentration had positive correlations with O_3 (r=0.700) and PM_{10} (r=0.479), although the correlations were not statistically significant. In conclusion, it seems that the ultra-fine particles (UFPs, d < 0.1 um ≤ 100 nm) may affect the human respiratory and circulatory systems because they have charged aerosol characteristics. Based on these results, it was found that the operation of the copier was an important influential factor of the charged aerosol generation level in the copy center, and that the positive ions were dominant.

Key words: Charged aerosol, Corona discharge, Copy center, Copier machines, Indoor air pollutants

Introduction

Information technology and electric technology have rapidly developed and are changing the home and business environments. IT development has increased the types and quantities of office equipment that office workers must use[1)]. Daily-use office equipment now include desktop computers and accessories, laser printers, scanners, fax machines, and copiers.

Studies on harmful pollutants from office equipment dwell mainly on their toxic impacts and diverse pollutant exposure characteristics. Wolkoff *et al.*[2)] found that office equipment emit O_3, particle matters, volatile

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organic compounds (VOCs), and semi-volatile organic compounds (SVOCs), and that paper emits VOCs, SVOCs, and particles during printing and copying. They reported that ozone and particle matters are related to occupational symptoms including those related to the eyes and nose such as pharyngolaryngitis, headache, and fatigue[3, 4]. Wensing *et al*.[5] reported the aerosol particle sizes emitted from 10 different hardcopy machines. In all cases, ultra-fine particle (UFP, d < 0.1 um ≤ 100 nm) emission was dominant. It was found in the study that UFPs are continuously emitted when large particles (e.g., toner powder) are detected at low concentrations during the operation of the hardcopy machine[4–7]. Thus, many researchers reported that UFPs are generated when laser printers or copiers are being used[8–10].

Studies on the pollutant emission of office equipment have been mainly about O_3, VOCs, SVOCs, and UFPs, which are caused by direct emissions from diverse office equipment in operation. When high-voltage equipment, including copiers, laser printers, and electrical-precipitation-type air cleaners, are used, the aerosol in the air takes on electrical characteristics through the process of corona discharge, and a secondary pollutant, called "charged aerosol", is formed around the equipment. Corona discharge often occur from electrodes that have a several thousand volts. In particular, it was reported that when UFPs are charged according to the electrical environment in the air, they can combine with heavy-metal and gas-phase materials due to condensation, one of the important physical characteristics of charged aerosol, and can be easily deposited when inhaled by humans[11]. It was reported that charged aerosol generation is closely related to the ozone generation mechanism[12]. The charged aerosol near outdoor high-voltage transmission lines was reported to have increased with an increase in humidity, and to have moved significantly away from the lines according to the wind direction and speed[13].

The National Radiological Protection Board (NRPB) of the UK mentioned in its 2004 report the charged aerosol effects on the human body due to the corona discharge in a high electromagnetic field environment. According to this report, charged aerosol has a higher probability of being deposited in the human airway or skin than uncharged aerosol and adversely affects human health[11]. The human health effects of charged aerosol were first studied by Wilson (1947)[14], based on the increase in the diseases of the human respiratory and circulatory systems from the charged aerosol generation in the air. According to Fews *et al*., the aerosol charge rate near high-voltage transmission lines was 7–42%, and 35–57% of people exposed to such aerosol may develop lung cancer due to the charged aerosol[15]. Chan *et al*. reported that the human body deposition rate of the charged aerosol (2–7 um) was statistically higher than that of the uncharged aerosol[16]. Cohen *et al*. found that the deposition rate of charged ultra-fine aerosol was at least three times higher than that of neutrally charged aerosol[17]. Melandri *et al*. studied the effects of charged aerosol in the air on the human body and reported that the negative and positive charge deposition rates were 15% and 30%, respectively, and that aerosol particles with diameters of 0.6–1.0 um were charged with 50–100 e of aerosol per particle[18].

Copier production in Korea abruptly increased to 432,570 units in 2006 from 247,525 units in 2000, or by 74.76%, and from 420,480 units in 2005, or by 2.88%[19]. According to a survey of the copying status in Korea[20], there is 1.0 copier and 3.6 printers in each office, and 16 people use one equipment. As copying is becoming an independent service (of copy centers) in line with the increasing copying demand, the number of copy centers in Korea is increasing. There are now more than 1,000 copy centers around universities, and more if the copy centers in the universities themselves are included. The workers in the copy center are easily exposed to diverse pollutants because they work at a very short distance to the copier.

Accordingly, this study was performed to evaluate the charged aerosol generation characteristics in copy centers where copiers are used as the major means of business. The indoor and outdoor conditions in 10 copy centers were measured to compare their charged aerosol currents and charged aerosol concentrations. One copy center was continuously monitored for six days to identify the difference in the charged aerosol generation characteristics according to the copier operation. The pollutant sources that could influence the charged aerosol generation were also evaluated.

This study is meaningful in that it is a basic study on the characteristics of charged aerosol generation, which is a secondary mechanism, since it widens the scope of previous studies on the emission characteristics of direct pollutants such as UFPs.

Subjects and Methods

Eight-hour and one-hour charged aerosol currents and charged aerosol concentrations in 10 copy centers were simultaneously measured indoors and outdoors. For each copy center, the charged aerosol was monitored indoors and outdoors for six days for eight hours per day, and the charged aerosol and gas-phase materials were continuously monitored for 48 h.

Table 1. Characteristics of each sampling site

Site	Type of Building	Volume (m^3)	Type of Business	No. of Copiers	Surroundings
A	First-floor monolithic construction	175	Combined copy & Other	4	Adjacent footpath and road
B	First-floor monolithic construction	206.3	Specialization in copy	7	Adjacent footpath and road
C*	First-floor monolithic construction	128.7	Specialization in copy	4	Adjacent footpath and road
D	First-floor monolithic construction	89.1	Specialization in copy	4	Adjacent footpath and road
E	Third-floor monolithic construction	85.8	Specialization in copy	4	Adjacent footpath
F	First-floor monolithic construction	123.8	Specialization in copy	5	Adjacent footpath and road
G	Second-floor monolithic construction	99	Specialization in copy	4	Adjacent footpath and road
H	Third-floor monolithic construction	600.6	Specialization in copy	7	Adjacent footpath and road
I	Second-floor monolithic construction	99	Specialization in copy	5	Adjacent footpath and road
J	Third-floor monolithic construction	123.8	Specialization in copy	4	Adjacent footpath and road
Control	Fourth-floor monolithic construction	316.8	-	-	-

*In this site, the measurements were performed for both a short time (8 h/day) and a long time (continuously for six days).

Site selection for the measurement

To identify the generation characteristics of charged aerosol, this study was performed in copy centers where copiers are used as the major means of business. Copy centers that are under normal operations and have four or more copiers were selected. Table 1 shows the summary of the selected copy centers. A lecture room in the university that had a similar indoor environment, except that it did not have copiers and high-voltage equipment, was selected as the control site.

The indoor measurements in the 10 copy centers were performed for eight hours from 10 a.m. to 6 p.m., considering the copy center business hours. The measurement devices were installed 1.2–1.5 m from the floor at the center of the space, considering the breathing zone of the workers.

The measurements were also performed in the same way at the control site. The outdoor measurements were continuously performed for one hour after the indoor measurements were completed.

Six-day continuous measurements were performed in a copy center (Site C) to identify the correlation between the charged aerosol generation and pollutants and to more quantitatively evaluate the charged aerosol generation characteristics according to the copier operation. The indoor measurements were performed for more than 12 h per day from 9:30 a.m. to 9:30 p.m. for six days. The outdoor measurements were performed in the same manner as were the indoor measurements at a point 20 m from the entrance, which was least influenced by the indoor environment.

Real-time monitoring was performed for 48 h to examine the correlation between the copying volume and the charged aerosol generation. The copying volume data were obtained from the Copy Log List that was automatically stored in the copier. The Copy Log List quantitatively shows the copying volume and the copying status by time.

To identify the correlation between the charged aerosol generation and pollutants, fine particles (PM10), ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), temperature, and humidity were measured.

Measurement instruments

The TSI model 3068B aerosol electrometer (TSI Incorporated, St. Paul, MN) was used to identify the indoor and outdoor charged aerosol generation characteristics. This device measures the 0.002–5.0 um-diameter charged aerosol current (fA) in real time (at 10 s sampling interval) in the air. The charged aerosol concentration (ions/cm^3) was automatically calculated using the following equation.

$$N = \frac{I}{e \times n_p \times q_e} \quad (1)$$

where:
N = particle number concentration (ions/cm^3);
e = elementary unit of charge, 1.602×10^{-19} Coulombs;
n_p = number of charges per particle;
q_e = flow rate (cm^3/s); and
I = electrical current (Amps).

The indoor particle number concentration was measured using a TSI Model 3781 micro-environment water-based condensation particle counter (ME-WCPC, TSI Incorporated). This device collects particles in the air with diameters of 6 nm to 3.0 um and measures the particle number concentration at 10s intervals in real time.

Of the indoor pollutants, PM10 was measured using a mini-volume air sampler (PAS201, Air-Metris, USA). Continuous measurement was performed for more than eight hours from 10 a.m. to 6 p.m., considering the business hours of the copy centers.

The magnetic field levels in the copy centers were measured using EMDEX II (ENERTECH, Inc.). EMDEX II is a three-axis electric and magnetic field digital exposure system that was developed by EPRI (Electric Power Research Institute). With a measurement band of 40–800 Hz, 10s interval sampling was performed in real time. After the measurement, the data were transferred to the main computer using the exclusive program EMCALC 2007.

The indoor air quality was monitored using the TG 502 toxic gas probe with PID (GrayWolf, USA).

Results

For the indoor and outdoor points of the 10 copy centers, the effective levels (%), charged aerosol currents, and charged aerosol concentrations were compared.

Aerosol in the ambient has a natural electric charge and has a current between –1 femto ampere(fA) to +1 fA usually. This is called "noise level current". The effective levels are in percentage values, excluding the noise level current (–1 fA – +1 fA).

As shown in Table 2, the indoor and outdoor effective levels were 93.4% and 82.4%, respectively. The indoor and outdoor effective levels at the control site were 66.2% and 99.7%, respectively. The indoor effective levels of the copy centers were 1.4 times higher than that of the control site, and the I/O ratios of the copy centers were 1.1 on the average. The indoor and outdoor negative ion currents were similar, but the average indoor and outdoor positive ion current was about 4.2 times higher indoors than outdoors. The average indoor negative and positive ion currents at the control site were 48% and 8.1% of those at the copy centers, respectively.

The average charged aerosol concentration in the copy center was about 4.6 times higher than that outdoors and about 19.5 times higher than that of the control site. Excluding one site (Site 8) where the measurement was not performed due to the abnormal operation, nine copy centers had an average I/O ratio of 4.6 (0.7–13.1). The charged aerosol concentration was higher indoors than outdoors in seven copy centers. The average I/O ratio at the control site was 0.2, and the charged aerosol concentration was higher outdoors than indoors. The fine particle (PM10) level in the copy center was about 3.7 times higher than that in the control site.

Figure 1 shows the median, first and third quartiles, and minimum and maximum at each site using the

Table 2. Indoor and outdoor charged aerosol current (fA), concentration (ions/cm^3) and effective level (%) for each site

Site	Charged Aerosol Current (fA)						Charged aerosol concentration (ions/cm^3)			PM_{10} (μg/m^3)
	Indoor Mean ± SD (–) ion	Indoor Mean ± SD (+) ion	Effective level (%)	Outdoor Mean ± SD (–) ion	Outdoor Mean ± SD (+) ion	Effective level (%)	Indoor	Outdoor	I/O ratio	Indoor
A	–13.7 ± 10.8 (–74.5 ~ –1.0)	24.4 ± 16.8 (1.0 ~ 110.1)	93.3	–2.8 ± 1.8 (–9.4 ~ –1.0)	6.3 ± 12.5 (1.0 ~ 38.8)	60.8	824.6 ± 611.1	161.1 ± 314.5	5.1	66.7
B	–14.8 ± 15.7 (–84.6 ~ –1.1)	90.5 ± 81.3 (1.0 ~ 450.9)	99.4	–3.5 ± 2.2 (–12.3 ~ –1.0)	7.7 ± 6.4 (1.0 ~ 43.1)	84.4	3,167.8 ± 3,031.2	242.6 ± 218.7	13.1	570.8
C	–2.6 ± 2.7 (–35.8 ~ –1.0)	32.5 ± 37.2 (1.0 ~ 163.3)	80.6	–8.4 ± 8.0 (–23.7 ~ –1.2)	5.3 ± 8.2 (1.0 ~ 83.1)	89.4	1,082.1 ± 1,359.4	234.5 ± 289.4	4.6	198.5
D	–4.2 ± 2.7 (–18.9 ~ –1.1)	15.4 ± 12.7 (1.0 ~ 85.5)	96.6	N.D[#]	20.1 ± 12.5 (3.5 ~ 64.6)	98.5	561.0 ± 475.4	755.9 ± 468.8	0.7	508.3
E	–2.2 ± 0.9 (–5.1 ~ –1.0)	63.6 ± 65.8 (1.0 ~ 289.7)	90.5	–3.2 ± 2.6 (–6.7 ~ –1.1)	7.0 ± 5.2 (1.2 ~ 20.3)	88.2	2,205.1 ± 2,451.6	252.1 ± 194.7	8.7	386.7
F	–1.9 ± 0.7 (–4.3 ~ –1.1)	17.3 ± 16.7 (1.0 ~ 140.4)	96.9	–2.6 ± 2.1 (–13.8 ~ –1.0)	13.3 ± 17.6 (1.0 ~ 63.3)	76.9	642.8 ± 629.8	139.5 ± 247.2	4.6	87.5
G	–1.6 ± 0.9 (–6.3 ~ –1.0)	39.5 ± 50.9 (1.0 ~ 450.6)	95.3	–8.2 ± 10.8 (–48.2 ~ –1.0)	10.9 ± 10.0 (1.0 ~ 73.3)	76.9	1,464.1 ± 1,905.8	398.3 ± 378.0	3.6	291.7
H	–3.8 ± 1.5 (–7.8 ~ –1.0)	29.1 ± 21.5 (1.0 ~ 88.1)	93.7	Missing[##]	Missing	–	948.4 ± 818.1	Missing	–	425.0
I	–1.80 (–1.8 ~ –1.8)	106.4 ± 96.2 (3.5 ~ 479.5)	100	–5.3 ± 11.4 (–35.8 ~ –1.2)	11.7 ± 19.2 (1.0 ~ 211.7)	91.4	3,989.2 ± 3,608.5	423.5 ± 716.4	9.4	570.0
J	–3.4 ± 2.3 (–51.7 ~ –1.0)	8.5 ± 5.3 (1.0 ~ 95.2)	87.7	–2.3 ± 3.4 (–18.1 ~ –1.0)	9.2 ± 11.9 (1.0 ~ 76.4)	75.3	238.4 ± 188.8	325.0 ± 436.5	0.7	98.5
Control	–2.4 ± 1.2 (–4.2 ~ –1.0)	3.5 ± 4.8 (1.0 ~ 12.5)	66.2	–2.6 ± 0.5	N.D	99.7	77.3 ± 102.6	479.1 ± 92.1	0.2	85.6
Total[###]	–5.0 ± 4.9	42.7 ± 33.2	93.4	–4.5 ± 2.5	10.2 ± 4.5	82.4	1,512.3 ± 1,230.0	325.8 ± 187.8	4.6	320.3

[#]Not Detected; [##]the outdoor measurement data were lost; [###]Control value not included.

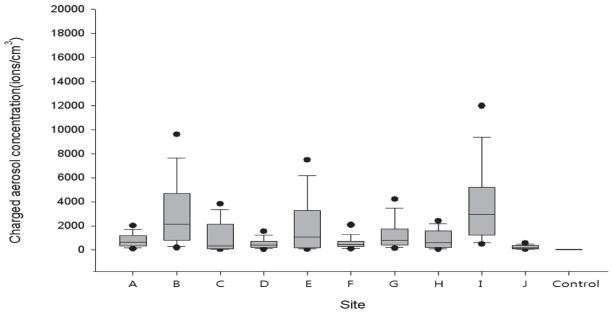

Fig. 1. Distribution of the charged aerosol concentration in each site.

The large box represents the inter-quartile range (IQR), and the horizontal line that divides the box is the median. The solid dots represent values that are three times the P_{75}–P_{25} IQR range, respectively.

charged aerosol concentration box plot. As shown in the figure, the variation was higher than in the control site.

Table 3 shows the daily changes during the business hours in a week and the correlation with the copying volume. The average negative ion current was lower indoors than outdoors, but the average positive ion current was about 4.9 times higher indoors than outdoors.

The average I/O ratio of the charged aerosol concentration was 4.6, and the charged aerosol concentration was higher indoors than outdoors, except on Day 6.

Figure 2 shows the trend of the charged aerosol current for 48 h. It was measured to examine the charged aerosol generation characteristics according to the copier operation. As shown in the figure, the charged currents significantly changed on Days A and B, when the copier was in operation, whereas the charged currents were relatively stable when the copier was not in operation.

Table 4 shows the charged aerosol currents and effective levels and the average charged aerosol concentration on Days A and B according to the copier operation. When the copier was being turned on and off, the positive ion current was about 2.5 times higher than the average negative ion current. The $T_{Turn\text{-}on}/T_{Turn\text{-}off}$ ratio, which represents the average charged aerosol concentration ratio at the time when the copier was in operation and not in operation, was 1.4.

Table 5 shows the daily indoor air pollutant concentrations in the copy center. The average particle concentrations differed daily, but not at statistically significant degrees ($p>0.05$). The average magnetic field was relatively constant. No nitrogen oxide or NO_2 and only a minimum amount of NO was detected. The fine particle level was about 1.2 times higher indoors than outdoors.

Table 6 shows the correlation between the charged aerosol currents (negative and positive ions) and the charged aerosol concentrations and indoor air pollutants. As NO_2 was not detected and the NO concentration was very low, they were excluded from the correlation analysis.

The correlation between the positive ion currents and the effective level was positive ($p<0.05$) at 0.940, and the correlation between the positive ion currents and the charged aerosol concentration was strongly positive ($p<0.01$) at 0.994. The correlation between the effective level and the charged aerosol concentration was positive ($p<0.01$) at 0.938, and the correlation between

Table 3. Indoor and outdoor charged aerosol current (fA), concentration (ions/cm^3) and effective level (%) for six workdays

Day	Charged Aerosol Current (fA)						Charged aerosol concentration (ions/cm^3)		I/O ratio
	Indoor Mean ± SD		Effective level (%)	Outdoor Mean ± SD		Effective level (%)	Indoor	Outdoor	
	(–) ion	(+) ion		(–) ion	(+) ion				
Day 1	–6.9 ± 4.4 (–19.3 ~ –1.0)	17.5 ± 12.0 (1.0 ~ 60.8)	97.5	–6.2 ± 6.05 (–37.2 ~ –1.00)	4.0 ± 4.9 (1.0 ~ 137.1)	93.8	611.8 ± 455.1	186.4 ± 190.8	3.2
Day 2	–27.4 ± 22.1 (–71.1 ~ –1.0)	29.4 ± 16.4 (1.1 ~ 90.62)	99.8	–3.2 ± 1.89 (–20.0 ~ –1.01)	3.6 ± 1.8 (1.0 ~ 32.7)	97.1	1,104.0 ± 619.9	135.9 ± 72.3	8.1
Day 3	–4.6 ± 2.8 (–15.3 ~ –1.0)	64.0 ± 37.6 (1.02 ~ 129.6)	99.1	–7.5 ± 10.5 (–186.6 ~ 1.0)	5.1 ± 6.0 (1.0 ~ 84.3)	85.6	2,321.1 ± 1,449.2	200.1 ± 296.5	11.6
Day 4	–3.7 ± 5.2 (–114.4 ~ –1.0)	3.9 ± 8.1 (1.0 ~ 232.3)	75.0	Missing#	Missing	–	114.0 ± 253.3	Missing	–
Day 5	–13.6 ± 8.2 (–36.4 ~ –1.0)	28.5 ± 36.9 (1.04 ~ 927.1)	97.2	–2.3 ± 1.9 (–36.6 ~ –1.00)	3.7 ± 3.3 (1.0 ~ 33.6)	76.0	742.6 ± 962.7	94.7 ± 82.6	7.8
Day 6	–5.0 ± 10.8 (–124.5 ~ –1.0)	4.5 ± 3.5 (1.0 ~ 23.5)	77.0	–6.5 ± 3.7 (–13.7 ~ –1.00)	8.2 ± 3.8 (1.0 ~ 64.5)	89.7	147.3 ± 337.5	291.2 ± 142.5	0.5
Total	–10.2 ± 9.1	24.6 ± 22.2	90.9	–5.2 ± 2.2	4.9 ± 1.9	88.4	840.1 ± 816.3	181.7 ± 74.1	4.6

#The outdoor measurement data were lost.

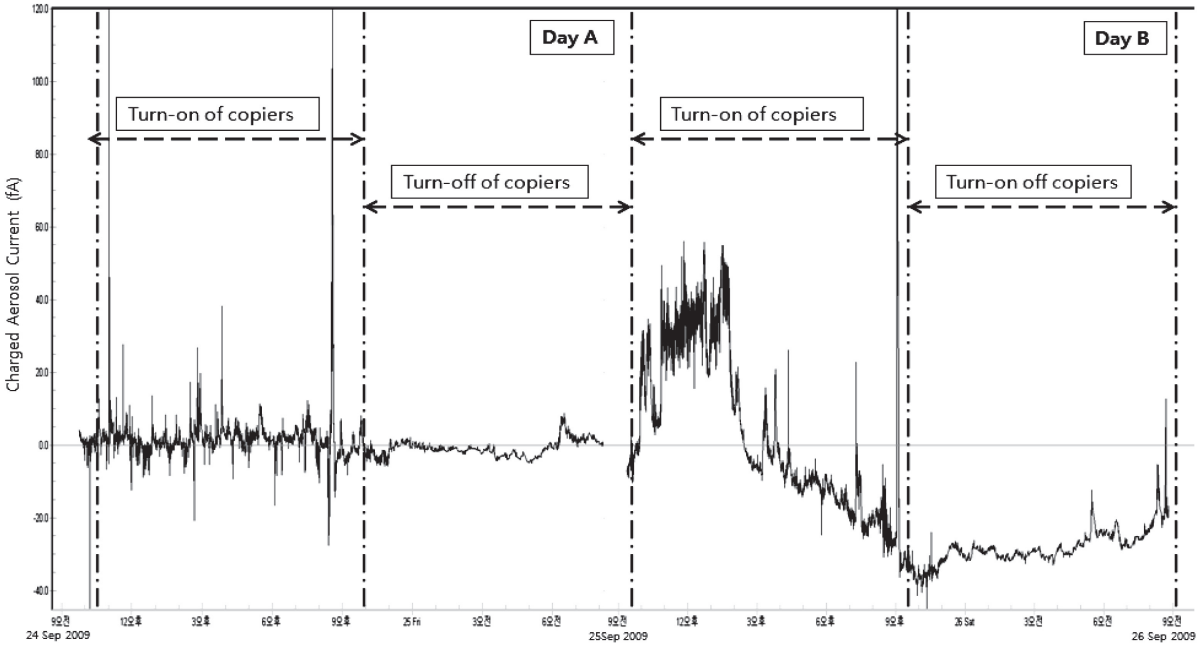

Fig. 2. Variations in the charged aerosol current (fA) in 48 h.

Table 4. Charged aerosol current (fA) and effective level for turn-on time and turn-off time of copiers

		Charged Aerosol Current (fA)			Charged aerosol concentration (ions/cm^3)	$T_{Turn\text{-}on}$ /$T_{Turn\text{-}off}$ ratio
		Mean ± SD (Range)		Effective level (%)	Mean ± SD (Range)	
		(–) ion	(+) ion			
Day A	Turn-on	–3.3 ± 2.9 (–27.5 ~ –1.0)	3.9 ± 6.9 (1.0 ~ 120.3)	74.4	141.7 ± 226.5	1.3
	Turn-off	–2.5 ± 2.8 (–114.4 ~ –1.0)	3.2 ± 8.1 (1.0 ~ 232.3)	70.7	105.7 ± 208.8	
Day B	Turn-on	–10.7 ± 5.9 (–25.7 ~ –1.0)	26.1 ± 13.2 (1.0 ~ 55.9)	96.8	1,048.3 ± 179.7	1.5
	Turn-off	–27.9 ± 4.7 (–47.3 ~ –5.3)	8.9 ± 2.6 (6.7 ~ 12.7)	94.9	672.8 ± 473.9	
Total	Turn-on	–7.0 ± 5.1	15.0 ± 15.7	85.6	595.0 ± 641.0	1.4
	Turn-off	–12.2 ± 17.9	6.0 ± 3.9	82.8	389.3 ± 401.0	

Table 5. Indoor air pollutants (IAP) levels for each day

Day	Number conc. (particles/cm^3)	Magnetic field (mG)	NO (PPM)	O_3 (PPM)	Temp[#] (°C)	RH[##] (%)	PM_{10} (μg/m^3) Indoor	Outdoor
Day 1	58,708 ± 23,510 (22,220~349,000)	2.44 ± 0.18 (1.23~3.38)	0.03 ± 0.04 (0.00~0.30)	0.02 ± 0.02 (0.01~0.07)	28.1 ± 0.05 (26.1~29.0)	48.5 ± 2.83 (44.4~55.4)	91.6	–
Day 2	43,995 ± 19,025 (14,160~155,800)	2.45 ± 0.19 (1.97~3.18)	2.12e–3 ± 0.01 (0.00~0.20)	0.02 ± 0.001 (0.01~0.05)	29.4 ± 0.84 (26.4~30.4)	48.7 ± 3.98 (41.8~56.1)	95.8	71.8
Day 3	66,918 ± 32,093 (20,280~304,600)	2.45 ± 0.15 (2.09~4.31)	2.01e–3 ± 0.02 (0.00~0.07)	0.02 ± 5.82e–3 (0.01~0.04)	27.8 ± 0.89 (25.1~29.1)	66.2 ± 2.69 (60.4~73.2)	76.7	66.9
Day 4	45,170 ± 19,327 (14,180~228,610)	2.38 ± 0.19 (1.96~3.31)	7.08e–5 ± 2.66e–3 (0.00~0.30)	0.02 ± 5.6581e–3 (0.01~0.06)	29.3 ± 0.66 (27.2~30.5)	56.8 ± 2.46 (52.4~63.2)	88.1	84.2
Day 5	46,744 ± 19,008 (20,300~359,800)	2.36 ± 0.16 (1.19~3.13)	2.24e–3 ± 0.02 (0.00~0.50)	0.02 ± 4.70e–3 (0.01~0.07)	27.7 ± 1.16 (25.7~30.3)	57.6 ± 5.18 (45.2~69.3)	89.2	78.6
Day 6	37,545 ± 15,241 (9,839~156,000)	2.38 ± 0.17 (1.92~2.96)	1.06e–4 ± 4.22e–3 (0.00~0.20)	0.02 ± 3.92e–3 (0.01~0.04)	28.4 ± 0.82 (26.5~30.3)	51.7 ± 3.44 (42.5~61.3)	37.1	34.2
Total	49,845 ± 10,836	2.41 ± 0.04	0.006 ± 0.01	0.02	28.5 ± 0.77	54.9 ± 6.75	79.8	67.1

[#]Temperature (°C); [##]Relative Humidity (%).

Table 6. Correlation between the charged aerosol and the indoor air pollutant (IAP) factors

	(–) Ion[1]	(+) Ion[2]	E.L.[3]	C.A. Conc.[4]	N. Conc.[5]	M.F.[6]	O_3	Temp.[7]	Humid.[8]	PM_{10}
(–) Ion	1	0.458	0.618	0.485	–0.210	0.211	0.416	0.201	–0.449	0.416
(+) Ion		1	**0.940***	**0.994****	0.688	0.583	0.700	–0.460	0.344	0.479
E.L.			1	**0.938****	0.611	0.605	**0.870***	–0.393	0.031	0.572
C.A. Conc.				1	0.696	0.666	0.707	–0.413	0.299	0.454
N. Conc.					1	0.707	0.647	–0.496	0.471	0.478
M.F.						1	0.578	0.102	–0.111	0.326
O_3							1	–0.440	–0.222	0.541
Temp.								1	–0.437	0.146
Humid.									1	0.019
PM_{10}										1

**p<0.01, *p<0.05.
[1]Negative charged aerosol current (fA); [2]Positive charged aerosol current (fA); [3]Effective charged levels (%); [4]Charged aerosol concentration (ions/cm^3); [5]Number concentration (particles/cm^3); [6]Magnetic field (mG); [7]Temperature (°C); [8]Relative humidity (%).

the effective level and O_3 was positive (p<0.05) at 0.870.

Discussion

In this study, the charged aerosol generation characteristics due to the corona discharge during the copier operation were evaluated in the copier centers where the high-voltage copiers are used as major means of business. The copy centers near universities, which had the highest copying volume according to the report Copying Business Status in Korea (Korea Institute for Industrial Economics & Trade, 2003)[20], were selected to examine the charged aerosol generation characteristics.

The charged aerosol indoors and outdoors had to be simultaneously measured in real time, but there were not enough aerosol electrometer 3068B equipment for the simultaneous measurement. There was no significant difference between the real-time and consecutive measurements in the additional simultaneous measurement of a copy center (Site C), and, therefore, it seems that there was no problem with the consecutive measurements to find the I/O ratio.

The aerosol current exists in the air at a magnitude of –1 fA to +1 fA, which is the noise level. In this study, the percentage of the measured currents, from which the noise level was excluded, was represented as the effective level (%) to compare the indoor and outdoor charged aerosol generations. The average indoor effective level in the 10 copy centers was 93.4%, which is about 1.4 times higher than the 66.2% in the control site. This means that more aerosol is charged in the copy centers than in the control site, and that the condensation of the charged aerosol with other gas-phase materials or heavy metals is more probable in the copy centers. Bhavani *et al.* (in press)[21] reported according to the results of an animal test on respiratory system damage that, among the inflammatory response indices, IL-4, TNF-α, and IL-10 increased and IFN-γ decreased, which might imply adverse health effects. No significant difference was found in the effective level, however, according to the copier operation.

Morawaka *et al.*[22] and Wensing *et al.*[23] reported that the ultra-fine particle concentration increased with the increase in the copier operation time and the copying volume in the chamber. At Site C in this study, it was found, using the Copy Log List, that the effective level increased with the increase in the daily copying volume. This implies that a greater copying volume leads to a longer operation time, and thus, to an increase in the amount of the charged aerosol indoors.

The indoor and outdoor negative ion currents were similar, but the average positive ion current was about 4.2 times higher indoors than outdoors. The positive ion current was about 2.5 times higher during the copier operation time than during the non-operation time. It must be noted that the average indoor negative ion current in the control site was similar to that in the copy centers, whereas there was no positive ion in the control site. Therefore, it seems that the aerosol in the copy center was mainly charged with positive ions. Melandri *et al.*[24] reported, based on a study on humans, that the deposition of the negative and positive ions in the human body was 15% and 30%, respectively. Therefore, the aerosol around the copier was mainly positively charged during the copier operation, and the respiratory and circulatory systems of the people in the room and the relevant workers might have been affected.

The charged aerosol concentration in the copy center was about 4.6 times higher than outdoors. It

was 19.5 times higher than that in the control site (77.3 ions/cm^3). Especially, the charged aerosol concentration ratio (copier operation/non-operation) was 1.4. There has been no prior study on the measurement of the indoor charged aerosol concentration in a normal indoor environment, and there have been only a few limited studies in a laboratory environment. According to the study of J-Fatokun *et al.*[25], in which the aerosol electrometer 3068B that was used in this study was also used, the charged aerosol concentration in the air was 84 ± 49 ions/cm^3, and the charged aerosol concentration in the copy centers was 18 times higher. Direct comparison is difficult, however, because of the different measurement conditions, but the results indicate that the charged aerosol concentration in the copy centers significantly increased.

To evaluate the correlation between the charged aerosol generation and the indoor air pollutants in the copy centers, the aerosol concentration (particles/cm^3), magnetic field, NO_2, NO, O_3, fine particles (PM10), temperature, and humidity were measured. Copiers and laser printers are known to be important sources of indoor pollutants including granular materials, O_3, VOCs, and SVOCs[9,26]. In particular, many studies are being performed on ultra-fine particles (<0.1 um), which are emitted from copiers.

ME-WCPC equipment was used to measure the number of particles (6 nm – 3 um). The average indoor aerosol concentration in the copy centers was 49,845.4 particles/cm^3. He *et al.*[9] reported that the average aerosol concentration in a typical office was 6,500 particles/cm^3, that 40% ultra-fine particles were emitted from 61 laser printers, and that the temperature increase during the operation of the printers was an important cause of the particle emission in their study. Therefore, the aerosol concentration in the copy centers was about 7.7 times higher than that in a normal office, and it seems that the copier operation was the main cause of the increase in the aerosol generation. There are no clear study results yet on the mechanisms of ultra-fine particle formation[21] and charged aerosol generation. It seems that diverse further studies are needed.

As mentioned, O_3 is the indoor air pollutant that is generated by the operation of copiers and printers, and it is known to be closely related with the charged aerosol and O_3 generation mechanisms[12]. The O_3 concentration in the copy centers was 0.02 ppm, which was lower than the indoor air quality standard in Korea (0.06 ppm). In the analysis of the correlation between the indoor charged aerosol generation and the air pollutants, the charged aerosol concentration had high positive correlations with O_3 (0.700) and the fine particles (0.479). A portable device (TG-502) was used to measure the O_3, so that the real-time concentration could be calculated, but the allowable detection scope was very limited. This study had another limitation, though. Considering that the particles from the copiers were ultra-fine particles, 2.5 um ($PM_{2.5}$) or less particles should have been measured, instead of the 10 um (PM_{10}) or less particles.

Therefore, a further study is needed to examine the charged aerosol generation and its effect on pollutants by measuring the concentration using the certified measurement method for pollutants, including 2.5 um ($PM_{2.5}$) or less fine particles, O_3, VOCs, and SVOCs, and by collecting precise data on the toner materials.

Though the number of samples in this study and the study method were somewhat limited, it is expected that the results of this study will be used to examine the health effects on copy center workers and other users of high-voltage equipment such as copiers and laser printers.

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