Influence of air humidity and the distance from the source on negative air ion concentration in indoor air

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Abstract

Although negative air ionizer is commonly used for indoor air cleaning, few studies examine the concentration gradient of negative air ion (NAI) in indoor environments. This study investigated the concentration gradient of NAI at various relative humidities and distances from the source in indoor air. The NAI was generated by single-electrode negative electric discharge; the discharge was kept at dark discharge and 30.0 kV. The NAI concentrations were measured at various distances (10–900 cm) from the discharge electrode in order to identify the distribution of NAI in an indoor environment. The profile of NAI concentration was monitored at different relative humidities (38.1–73.6% RH) and room temperatures (25.2 ± 1.4 °C). Experimental results indicate that the influence of relative humidity on the concentration gradient of NAI was complicated. There were four trends for the relationship between NAI concentration and relative humidity at different distances from the discharge electrode. The changes of NAI concentration with an increase in relative humidity at different distances were quite steady (10–30 cm), strongly declining (70–360 cm), approaching stability (420–450 cm) and moderately increasing (560–900 cm). Additionally, the regression analysis of NAI concentrations and distances from the discharge electrode indicated a logarithmic linear (log-linear) relationship; the distance of log-linear tendency (λ) decreased with an increase in relative humidity such that the log-linear distance of 38.1% RH was 2.9 times that of 73.6% RH. Moreover, an empirical curve fit based on this study for the concentration gradient of NAI generated by negative electric discharge in indoor air was developed for estimating the NAI concentration at different relative humidities and distances from the source of electric discharge.

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1. Introduction

Artificial ionized air is generally employed in households and industries for indoor air cleaning or electrostatic elimination in manufacturing (Daniels, 2002; Crowley et al., 2004). The ionized air comprises negative and positive air ions (NAI and PAI), which can be gen-

erated simultaneously or separately through air ionization. NAI is widely applied to air cleaning in indoor environments to remove particles (Richardson et al., 2001; Lee et al., 2004; Mayya et al., 2004; Grinshpun et al., 2005), airborne microbes (Shargawi et al., 1999; Grinshpun et al., 2004), and volatile organic compounds (Wu and Lee, 2004). However, there is a lack of understanding the influences of air humidity and the distance from the source of NAI generation on NAI concentration in indoor air.

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Negatively charged air ions exhibit an average electric mobility of 1 to $2 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ (Krueger and Reed, 1976). The life of air ions is approximately 100 s (Parts and Luts, 2004), and is affected by humidity, temperature, etc. The chemical composition of NAI depends on the air composition and age of NAI (Parts and Luts, 2004). Luts and Salm (1994) show that superoxide (O_2^-) accounts for approximately 95% of the negatively charged species in NAI, and superoxide is more stable than the other primary NAI's. Other primary species such as O^- and OH^- may exist but in lower proportions than O_2^- (Huertas et al., 1978). Secondary NAI's such as CO_3^- , $\text{O}_2^-(\text{H}_2\text{O})$, and $\text{OH}^-(\text{H}_2\text{O})$ are generated by reactions between primary NAI and components in air (Skalny et al., 2004; Huertas et al., 1978). Sequentially, the hydration reactions produce complex cluster ions such as $\text{O}_2^-(\text{H}_2\text{O})_n$ in moist air (Huertas et al., 1978). Luts (1995) and Skalny et al. (2004) indicate that the cluster ions $\text{O}_2^-(\text{H}_2\text{O})_n$ and $\text{CO}_3^-(\text{H}_2\text{O})_n$ are dominant NAI's in moist air at steady state. However, if O_3 and NO_x exist in air, the dominant ions are $\text{NO}_3^-(\text{HNO}_3)_m(\text{H}_2\text{O})_n$ (Skalny et al., 2004; Luts and Salm, 1994; Perkins and Eisele, 1984). Furthermore, when the concentration of O_3 is greater than 25 ppm , O_3 completely suppresses the appearance of O_2^- and clusters involving O_2^- in both dry and moisture air (Skalny et al., 2004).

The effects of humidity on NAI are complicated and involve hydration and chemical reactions of NAI with H_2O in air. Luts and Salm (1994) indicate that an increase in the concentration of H_2O shifts the equilibrium of $\text{O}_2^-(\text{H}_2\text{O})_n$ toward larger cluster ions; Fujioka et al. (1983) demonstrate that the mobility of NAI decreased with an increase in absolute humidity. Richardson et al. (2003) and Goldstein et al. (1992) indicate that low concentrations of hydrogen peroxide (H_2O_2) are produced by superoxide in moist air. Although few studies examine the concentration gradient of NAI with distance changing, Kondrashova et al. (2000) indicate trace data which show the NAI concentrations at distances of 0.5 , 1.2 , and 3 m from ionization surface at a 50 kV dark discharge. The results of Kondrashova et al. (2000) show a logarithmic-linear trend between the NAI concentration and the distance from the ionization surface. However, the influences of air humidity and the distance from the source on NAI concentration are complicated and less understood.

2. Experimental details

This study considered the concentration gradient of NAI with varying relative humidity and distance from the discharge electrode without influence of O_3 and NO_x in an

indoor environment. The high-voltage negative discharge was operated as a point source for NAI generation. The concentrations of NAI at different relative humidities and space locations were detected by an air ion detector on different days with varying weather conditions during a period of 4 months.

2.1. Experimental system

As shown in Fig. 1, experiments were conducted in a closed room. The dimensions of the room are $9 \text{ m(L)} \times 5.7 \text{ m(W)} \times 3.3 \text{ m(H)}$. The NAI was continuously generated by electric discharge; the discharge voltage was maintained at negative 30.0 kV using a high-voltage power supply (Model SL300, SPELLMAN, USA). The discharge electrode was made of stainless steel, 5 cm long and with a tip of 0.1 mm in diameter. The electric discharge was at a height of 1.5 m above floor level. The current of electric discharge was less than 0.01 mA . The high-voltage power supply and supporting table were grounded to prevent electrostatic gathering for the safety of staff. The connecting places between power supply, high-voltage cord and discharge electrode were insulated with Teflon to prevent extra-discharge. To avoid the generation of byproducts O_3 and NO_x , the dark discharge was designed for NAI generation (Kondrashova et al., 2000). The concentrations of O_3 and NO_x were detected with an ozone detector (Model 400A, API, USA; lower detectable limit $<0.6 \text{ ppb}$) and an NO_x detector (Model 200, API, USA; lower detectable limit $<1 \text{ ppb}$), respectively. The NAI and PAI were detected with an air ion detector (Model IC-2000, METEX, Sweden). The resolution of air ion detector is $\pm 20 \text{ ion cm}^{-3}$ with a measuring range of zero to $8 \times 10^6 \text{ ion cm}^{-3}$. The electric mobility of the detectable air ion is over $0.5 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. The air ion detector was supported by a prop stand at a height of 1.5 m above floor level, and recorded data per second by a computer. The air ion detector and prop stand were grounded to avoid electrostatic interference. Since the NAI was detected at different space locations (10 , 20 , 30 , 70 , 130 , 210 , 260 , 360 , 420 , 450 , 560 , 610 , 800 , 900 cm), the floor was measured and marked with a scale. The relative humidity, temperature, carbon dioxide, and carbon monoxide were monitored by Q-Trak (Model 8551, TSI, USA), which recorded data per second. Moreover, the temperature at different space locations was also detected by air ion detector. The concentrations of carbon dioxide and carbon monoxide were checked as indicators for the event of polluted air infiltrating from outdoors. In addition, PM10 was monitored by Dust-Trak (Model 8520, TSI, USA) to confirm the clean state of the indoor air.

Fig. 1. Illustration of experimental system (a) high-voltage power supply (b) high-voltage electric cord with Teflon insulating sleeve (c) discharge electrode (d) electrode holding stand (e) ozone detector (f) nitrogen oxides detector (g) air ion detector (h) prop stand (i) scale (j) relative humidity and temperature monitor, Q-Trak (k) PM10 monitor, Dust-Trak (l) grounding.

2.2. Experiment conditions

The results in this study were obtained from monitoring of NAI concentration, temperature, relative humidity, PM10, NO_x and ozone on different days with varying weather conditions during a period of 4 months. The experimental conditions of temperature and relative humidity were not artificially created, but were passively controlled by the equilibrium of ambient weather. A total of 26 complete sets of data were collected during the 4 months. For examining the influence of relative humidity on NAI concentration, 7 complete sets of data which conformed to the NAI concentration distribution at $25.2\text{ }^{\circ}\text{C} \pm 1.4\text{ }^{\circ}\text{C}$ and relative humidity between 38.1% and 73.6% were selected for analysis.

The indoor air of the experimental room was ventilated by two air conditioners for 30 min before the experiments. The air conditioners were turned off during experiments in order to avoid air turbulence and air movement as far as possible. Then the negative discharge at 30.0 kV was switched on, and the environmental factors (relative humidity, temperature, PM10, ozone, and NO_x) were started to be monitored. After more than 1 h, the relative humidity and temperature were approaching stability, and, through the mechanism of particle removal by NAI, the PM10 was less than 0.010 mg m^{-3} . The results of our previous studies (Wu

and Lee, 2003) indicated that most of the aerosol particles were removed through NAI generation after 1 h. The number concentration of submicron aerosol particles was usually less than 3000 cm^{-3} in comparison with the 0.010 mg m^{-3} of PM10 in our previous studies. When the relative humidity, temperature, and PM10 were ready, the NAI concentration was measured at each space location for 5 min. The NAI concentration distribution with average NAI concentrations and standard deviations at different distances from the discharge electrode were then calculated.

3. Results and discussion

The results of ozone and NO_x measurements indicated that the concentrations of ozone and NO_x were less than 1 ppb in indoor air during the experiments of approximately 2 h because of the dark discharge with very low current employed. By the way, Boelter and Davidson (1997) and Rehbein and Cooray (2001) indicate that the most important parameter affecting generation of ozone and nitrogen oxides is the current of discharge. Prior to electric discharge, the backgrounds of NAI and PAI were both less than 500 ion cm^{-3} . After the negative electric discharge had been started, no PAI was detected. PAI's absence was owing to the fact that the enormous amount of NAI generated neutralized PAI.

3.1. Humidity

Fig. 2 depicts the average NAI concentration versus relative humidity at different distances from the discharge electrode at 25.2 ± 1.4 °C. The standard deviation of NAI concentration was between 1.1% and 5.2%, and closer to 5.2% when the level of NAI concentration was low. The relationship of average NAI concentration and relative humidity shown in Fig. 2 indicates that there were four slope trends at different space locations. The divisions of space locations into four trends were at 10–30 cm, 70–360 cm, 420–450 cm, and 560–900 cm from the discharge electrode.

3.1.1. Space location 10–30 cm

In the zone near the electrode (10–30 cm), the NAI concentration was lightly affected by relative humidity. At a distance of 10 cm, the concentration of NAI was approximately 2.2×10^6 ion cm^{-3} and remained constant even though relative humidity ranged between 38.1% and 73.6%. Although there was a slight variance in NAI concentration, near 1.3×10^6 ion cm^{-3} at a distance of 30 cm, the concentration was stable at different relative humidities.

3.1.2. Space location 70–360 cm

The concentration of NAI in the zone between 70 cm and 360 cm decreased when relative humidity increased. At a distance of 70 cm, the NAI concentration at 38.1% RH was 3.1 times the concentration of NAI at 73.6% RH. At a distance of 130 cm, the NAI concentration dramat-

ically declined with an increase in relative humidity. The NAI concentration ratios of 38.1% to 73.6% RH were 14.9, 10.2, 8.2, and 3.1 at 130 cm, 210 cm, 260 cm, and 360 cm, respectively. The ratio of NAI concentration decreased with distances from 130 to 360 cm; therefore, the concentration gradient of NAI decreased when the distance increased within 130 to 360 cm.

3.1.3. Space location 420–450 cm

At the space location between 420 cm and 450 cm, the NAI concentration became smooth and stable, especially at 450 cm. The NAI concentration ratios of 38.1% to 73.6% RH were 1.7 and 1.1 at a distance of 420 cm and 450 cm, respectively. In the zone between 420 cm and 450 cm, the concentration gradient of NAI approached an equable level and the concentration of NAI was between 1400 ion cm^{-3} and 1570 ion cm^{-3} , despite the changed level of relative humidity.

3.1.4. Space location 560–900 cm

In the farthest zone (560–900 cm), the relationship between NAI concentration and relative humidity moved in an opposite direction. The NAI concentration increased with an increase in relative humidity at a distance between 560 cm and 900 cm. With a relative humidity of 38.1% RH, the NAI concentration decreased at distances farther than 450 cm. However, the NAI concentration at 73.6% RH decreased very slowly as the distance increased. Therefore, the value of NAI concentration ratio of 38.1% to 73.6% RH was less than 1. Moreover, the values of NAI concentration ratio

Fig. 2. Average NAI concentration at different relative humidities and distances from the electric discharge electrode (temperature 25.2 ± 1.4 °C; standard deviation of NAI concentration 1.1–5.2%).

decreased with distance and were 0.44, 0.26, and 0.17 at a distance of 560 cm, 610 cm, and 900 cm, respectively.

The mechanisms from the effects of humidity include chemical reactions and the hydration of NAI. The chemical reaction of NAI and H_2O is a sink of NAI and depends on relative humidity (Richardson et al., 2003). The hydration of NAI is also a sink for electric mobility. If the size of hydrated NAI is too large, the hydrated NAI becomes a charged aerosol and is excluded from air ions because the electric mobility is too low for it to be an air ion (Hörrak et al., 1998). The mobility of air ions had to be higher than $0.5 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ because of the limitations of the air ion detector in this study. Nevertheless, the hydration of NAI is a stable process for NAI; for example, when the NAI hydrates, $\text{O}_2^-(\text{H}_2\text{O})_n$ and $\text{CO}_3^-(\text{H}_2\text{O})_n$ are dominant cluster ions in wet air at a steady state (Luts, 1995; Skalny et al., 2004). At the zone near the electrode, the NAI concentration was lightly affected by relative humidity, possibly due to the large amount of primary NAI continuously generated. On the contrary, the concentration of NAI decreased substantially with an increase in relative humidity between 70 cm and 360 cm. In this zone, more secondary NAI and hydrates may be produced and, therefore, the sink of NAI is significant. Furthermore, Parts and Luts (2004) indicate that the older ions are more affected by less abundant components in air. At the distances between 420 cm and 450 cm, the NAI concentration became smooth; a possible reason is the relatively stable hydrate of NAI existing at a low NAI concentration around 10^3 ion cm^{-3} . Smirnov (1992) indicates that the lifetime of $\text{O}_2^-(\text{H}_2\text{O})$ is 1.1×10^4 times that of $\text{O}_2^-(\text{N}_2)$, and the lifetime of $\text{O}_2^-(\text{H}_2\text{O})_2$ is 3.3 times that of $\text{O}_2^-(\text{H}_2\text{O})$. Therefore, NAI is more stable when the H_2O molecules in hydrate of NAI increase. In higher levels of relative humidity, an increase in the concentration of H_2O shifts the equilibrium of $\text{O}_2^-(\text{H}_2\text{O})_n$ toward larger cluster ions (Luts and Salm, 1994). At the distances between 560 cm and 900 cm, the concentration of NAI at a high relative humidity was higher than that at a low relative humidity. The reasonable explanation is that more stable NAI existed in more moisture air, so that the concentration of NAI increased with relative humidity at the farthest zone.

3.2. Distance

Fig. 3 shows the average NAI concentration versus the distance starting from the discharge electrode and at different levels of relative humidity. Fig. 4 shows the average NAI concentration versus the distance from the discharge electrode at relative humidities of 38.1 and 73.6% by example. In Figs. 3 and 4, the concentration

gradient of NAI demonstrates two tendencies. The first is a logarithmic linear (log-linear) tendency within a log-linear distance (λ) as shown in Fig. 4. The regression analysis of the average NAI concentration and distance from the discharge electrode showed that a log-linear regression line indicated a strong correlation between distance and NAI concentration within a specific distance (log-linear distance, λ). Regression results showed that the correlation coefficients (R^2) of the log-linear regression were 0.9527–0.9913 at different levels of relative humidities; and the regression equations were $y = 2.8 \times 10^6 \exp(-0.0162x)$ and $y = 2.8 \times 10^6 \exp(-0.0323x)$ for 38.1 and 73.6% RH, respectively, as shown in Fig. 4. Following the log-linear tendency, the second trend is the points out of the log-linear tendency which appeared as a similar horizontal tendency when the distances from the discharge electrode were larger than the distances within the log-linear tendency. The levels of NAI concentration in the horizontal trend were approximately 190 and 1440 ion cm^{-3} at the relative humidities of 38.1 and 73.6%, respectively. Moreover, the study of Kondrashova et al. (2000) also indicated a logarithmic-linear trend between the NAI concentration and the distance from the ionization surface with a correlation coefficient (R^2) of 0.9613 for the NAI concentrations as opposed to distances of 0.5, 1.2, and 3 m with a 50 kV dark discharge.

Table 1 summarizes the log-linear distance (λ) at different levels of relative humidity. The distance in log-linear ranges was a specific distance and decreased with an increase in relative humidity. The log-linear distances (λ) were 610, 580, 500, 420, 360, 280, and 210 cm at 38.1, 43.7, 52.6, 58.3, 63.5, 67.9, and 73.6% RH, respectively. The log-linear distance (λ) of 38.1% RH was 2.9 times the log-linear distance (λ) of 73.6% RH. Moreover, the experimental data in Figs. 3 and 4 indicates that the concentration of NAI was very stable near the discharge electrode. The NAI concentration $2.8 \times 10^6 \text{ ion cm}^{-3}$ at discharge source ($x=0$) was established by a calculated value for the intercept on the y-axis. Therefore, the regression equation shown in Fig. 4 can be formulated as:

$$y = 2.8 \times 10^6 \exp(ax), \quad (1)$$

where y is average NAI concentration (ion cm^{-3}), x denotes distance from the discharge electrode (cm), and a is a regression coefficient (cm^{-1}), a negative quantity that decreases with an increase in relative humidity. Table 1 summarizes the log-linear distance (λ) and correlation coefficient (a) at different levels of relative humidity and shows the factor α (cm^{-1}) transformed from the correlation coefficient (a) to simplify the empirical curve fit of concentration gradient of NAI.

Fig. 3. Average NAI concentration versus the distance from the discharge electrode at different relative humidities (standard deviation of NAI concentration < 5.2%).

3.3. Empirical curve fit

Considering the interactions between NAI concentration and two factors (relative humidity and distance),

an empirical curve fit based on this study was formulated to estimate the NAI concentration in indoor air. The NAI concentration is assumed a function of relative humidity (H_R) and distance from the discharge

Fig. 4. Average NAI concentration versus the distance from the discharge electrode at relative humidities of 38.1 and 73.6% RH for indicating the log-linear distance (λ) and the correlation equation by example.

Table 1

Logarithmic linear distance (λ), regression parameter (a) at different relative humidities

Relative humidity (%)	Log-linear distance (cm)	Regression parameter (a) (cm^{-1})
38.1	610	-0.0162
43.7	580	-0.0175
52.6	500	-0.0197
58.3	420	-0.0224
63.5	360	-0.0251
67.9	280	-0.0285
73.6	210	-0.0323

electrode (d). The concentration of NAI (C_{NAI}) can be expressed as:

$$C_{\text{NAI}} \cong f(H_R, d). \quad (2)$$

In Fig. 4, the regression Eq. (1) is expressed as:

$$C_{\text{NAI}} = 2.8 \times 10^6 \exp(ad). \quad (3)$$

3.3.1. Factor α calculation

In Table 1, factor α is the regression parameter (a) times a constant of -10^4 . Therefore, the regression parameter (a) is equal to $-10^{-4}\alpha$ and then Eq. (3) can be written as:

$$C_{\text{NAI}} = 2.8 \times 10^6 \exp(-10^{-4}\alpha d). \quad (4)$$

Fig. 5 plots relative humidity versus factor α . The regression analysis of factor α and relative humidity yielded a quadratic regression equation, $y = 0.10x^2 - 6.6x + 270$, and the correlation coefficient (R^2) was

0.9985, representing a strong correlation. Factor α and relative humidity (H_R) substitute into y and x , and the relation equation of factor α and relative humidity (H_R) can be represented as:

$$\alpha = 0.10(H_R)^2 - 6.6(H_R) + 270. \quad (5)$$

3.3.2. Log-linear distance (λ) calculation

Fig. 5 also depicts the data of log-linear distance (λ) versus relative humidity (H_R). The regression analysis of log-linear distance (λ) and relative humidity (H_R) indicated a linear regression line, $y = -11.6x + 1080$ with the correlation coefficient (R^2) of 0.9802. The results in Fig. 5 show that the log-linear distance (λ) correlated to relative humidity (H_R) in a linear relationship. Log-linear distance (λ) and relative humidity (H_R) substituted into y and x as well as the following equation:

$$\lambda = -11.6(H_R) + 1080. \quad (6)$$

The log-linear distance (λ) means a restriction on distance (d) from the discharge electrode, and is the upper boundary of the log-linear trend. If the distance (d) is less than or equal to the log-linear distance (λ), the concentration of NAI (C_{NAI}) can be estimated by Eq. (4). Therefore, the constraint can be expressed by the following equation:

$$d \leq -11.6(H_R) + 1080. \quad (7)$$

Furthermore, following the log-linear tendency in Figs. 3 and 4, the levels of NAI concentration versus distance were similarly horizontal, and therefore the

Fig. 5. Logarithmic linear distance (λ) ($\lambda = -11.6 H_R + 1080$) and factor α at different relative humidities ($\alpha = 0.10(H_R)^2 - 6.6(H_R) + 270$).

NAI concentration was regarded as a constant level for distance (d) larger than log-linear distance (λ). If distance (d) is larger than log-linear distance (λ), the concentration of NAI can be roughly estimated by substituting the log-linear distance (λ) for the distance (d) in Eq. (4). The empirical curve fit of concentration gradient of NAI in this study is summarized as follows:

$$C_{\text{NAI}} = 2.80 \times 10^6 \exp(-10^{-4}\alpha d), d \leq \lambda \text{ or } d = \lambda \text{ if } d > \lambda, \quad (4)$$

$$\alpha = 0.10(H_R)^2 - 6.6(H_R) + 270, \quad (5)$$

$$\lambda = -11.6(H_R) + 1080, \quad (6)$$

where C_{NAI} is NAI concentration (ion cm^{-3}), factor α stands for a coefficient (cm^{-1}), d means distance from the discharge electrode (cm), λ is log-linear distance (cm), and H_R stands for relative humidity (%).

3.3.3. Deviation of empirical curve fit

The empirical curve fit of this study was tested through three sets of measured data which were NAI concentrations at 45.1% RH (23.9 °C), 52.7% RH (25.3 °C) and 66.5% RH (24.5 °C) within 50 cm–900 cm. The deviations between measured average NAI concentrations and NAI concentrations from empirical curve fit were calculated, for example, the [measured average NAI concentration (ion cm^{-3}); NAI concentrations from empirical curve fit (ion cm^{-3}); deviation] at a distance of 200 cm from discharge electrode were [71,200; 83,309; 17.0%], [62,900; 51,377; 18.3%] and [15,600; 11,833; 24.1%] for 45.1% RH (23.9 °C), 52.7% RH (25.3 °C) and 66.5% RH (24.5 °C), respectively. The testing results indicated that the deviations of empirical model were almost less than 30% for distance less than 500 cm and less than 52% for distance larger than 500 cm. The deviations of empirical curve fit testing also showed that the deviations of empirical curve fit increased with the distance from the discharge electrode. Although the empirical curve fit was tested in this study, the general value of the NAI concentration in indoor air is not easy to obtain from these empirical formulas in different environmental conditions because some factors possibly influence the NAI concentration in an indoor environment without control, such as electrostatic gathering, particle concentration and electric field.

4. Conclusion

This study investigated the concentration gradient of NAI generated in indoor air. The effects of relative

humidity and distance from the discharge electrode were studied to better understand the NAI distribution. Results showed that the effect of relative humidity on concentration of NAI was considerable and complex. The relationships of NAI concentration and relative humidity indicated four slope trends at different space locations. In a major zone (70–360 cm), the NAI concentration greatly decreased with an increase in relative humidity. The correlation of NAI concentration and distance from the discharge electrode showed a logarithmic linear tendency within a specific distance (log-linear distance), which depended on the levels of relative humidity. Furthermore, the concentration of NAI can be expressed by $C_{\text{NAI}} = 2.80 \times 10^6 \exp(-10^{-4}\alpha x)$ and other constraint equations. Considering the NAI concentration and two factors (relative humidity and distance), an empirical curve fit of concentration gradient of NAI was developed to estimate the concentration of NAI in this study. The empirical equations are useful for the application of air ionizer in indoor environments.

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